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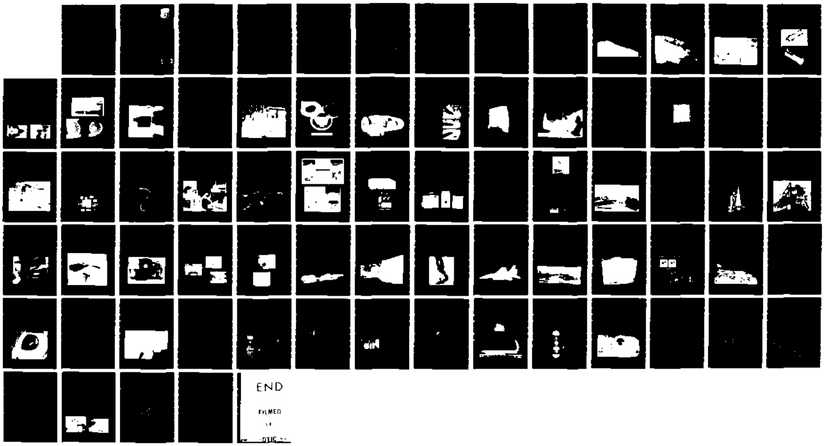

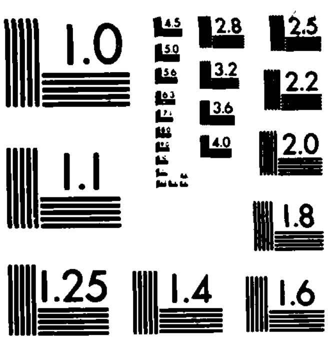

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AFWAL FY82 TECHNICAL ACCOMPLISHMENTS

Russell S. Hoff, Jr.

Programs Branch
Plans and Programs Office
Directorate of Management Services

JUNE 1983

FINAL REPORT FOR FISCAL YEAR 1982

Approved for public release; distribution unlimited

AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

Russell S. Hoff Jr.

RUSSELL S. HOFF, Jr.

FOR THE COMMANDER Integrated Programs Office

J.M. KELBLE
Deputy Director of Management Services
AF Wright Aeronautical Laboratories

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This report contains highlights of significant technical achievements made during FY 82. The document exemplifies the broad range of R&D activities being undertaken within AFWAL and the significance of the technological contributions being made to enhance Air Force operational capabilities. The accomplishments have been grouped by Laboratory to assist the reader in understanding the technologies covered. Points of contact have been identified for each accomplishment, if additional information on the subject is desired.

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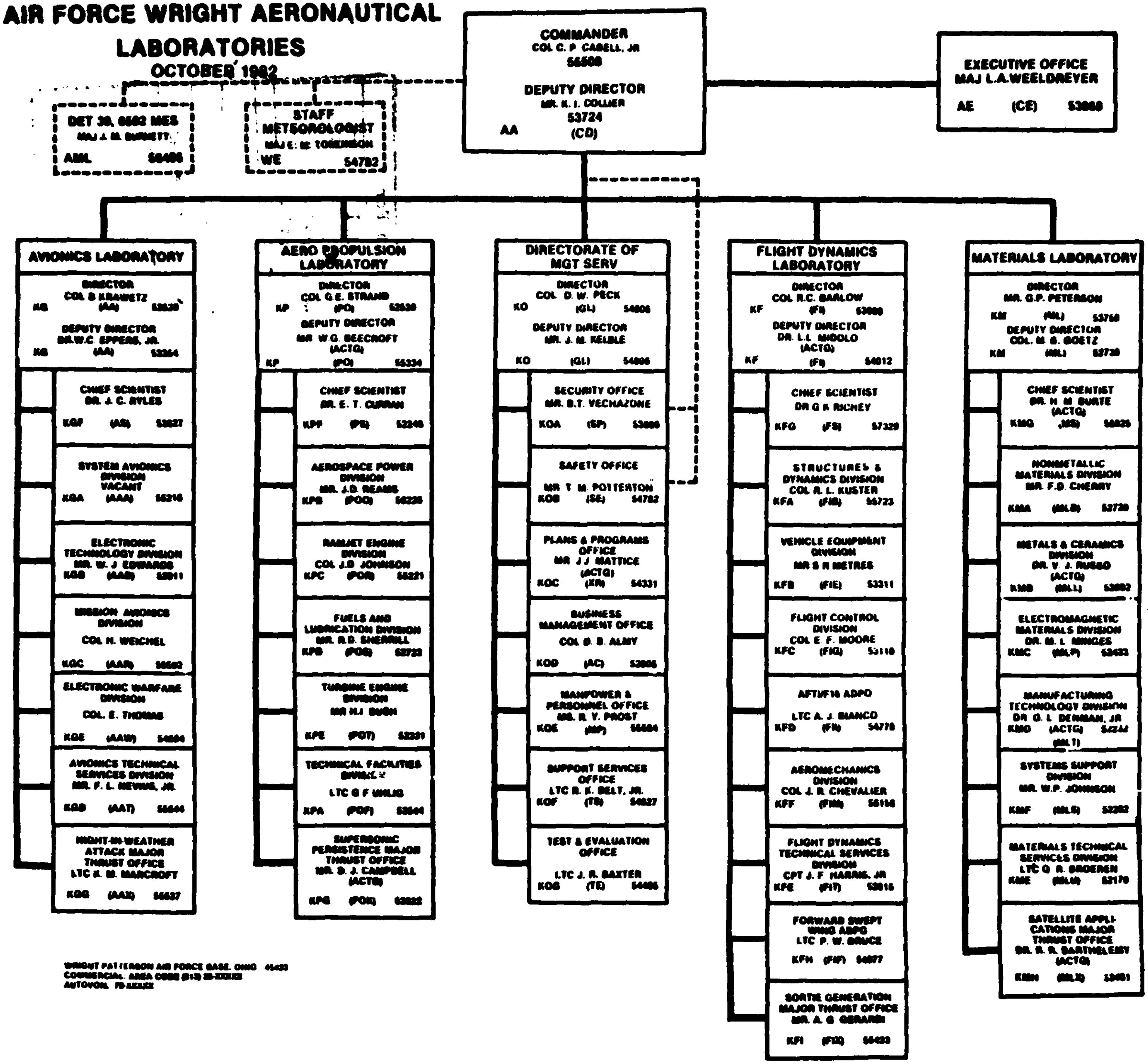
PREFACE

The Air Force Wright Aeronautical Laboratories (AFWAL) was established in July 1975 and was merged with the Aeronautical Systems Division (ASD) at Wright-Patterson Air Force Base in November 1982. Comprised of five organizational elements, i.e., the Aero Propulsion Laboratory (PO), the Avionics Laboratory (AA), the Flight Dynamics Laboratory (FI), the Materials Laboratory (ML), and the Directorate of Management Services, AFWAL plans and executes basic research, exploratory development, advanced development, manufacturing technology, and selected engineering development programs in a wide variety of technology areas. Although the major mission of AFWAL is to develop and expand the technology base, it is also responsible for providing technical expertise and assistance throughout the Air Force to support the acquisition of new systems and the resolution of developmental and operational problems.

This is the third annual AFWAL Technical Accomplishments report and contains accomplishments from all AFWAL Laboratories. The technologies developed as a result of these efforts have the potential to enhance future Air Force weapon systems and equipment or to improve producibility and/or reduced life cycle cost. Although the report was prepared by the Programs Branch, acknowledgement is made to all engineers who submitted the intitial technical narratives and associated illustrations. Special recognition also is made to Ms Helen Maxwell for her outstanding editoral contributions. Inquiries regarding individual subjects may be directed to the point of contact listed at the end of each accomplishment. Commercial telephone users should dial the number indicated. Telephone users with access to the Defense Communication System automatic voice switching network (AUTOVON) may dial 78 plus the last five digits. If additional copies are desired, call AV 785-4119. Comments for improving the format of this report are encouraged and should be addressed to AFWAL/XRPI (R.S. HOFF) Wright-Patterson AFB, Ohio 45433.

AIR FORCE WRIGHT AERONAUTICAL LABORATORIES

OCTOBER 1982



WRIGHT PATTERSON AIR FORCE BASE, OHIO 45433

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(4) IV MATERIALS LABORATORY

SECTION I
AERO PROPULSION LABORATORY

CONSTRUCTION COMPLETION OF FUELS AND LUBRICATION LABORATORY

Aero Propulsion Laboratory research and development on fuels, lubricants, and lubrication systems requires the use of sophisticated analytical equipment to characterize fuel and lubricant properties, develop fuels from alternate supply sources such as shale oil, and determine the combustion characteristics of new fuels under modern engine operating conditions. Previous facilities lacked the space, environmental controls, and safety conditions necessary to conduct this research.

Construction of the Fuels and Lubrication Laboratory began in July 1980 and was completed in June 1982. This 60,000 square foot, 12 million dollar facility provides laboratories for conducting chemical and instrumented fuels and lubricant analyses, lubrication and fuel system research, and fuel combustion studies. Also included are areas for fuel storage and fuel blending. This new facility will provide significantly new operating capabilities, in addition to improving current ones. The precise temperature and humidity control in the analytical laboratories will provide test result consistency previously unattainable. It will now be possible to do in-house lubrication system research using a jet engine simulator, bearing fatigue test equipment, and oil disposition equipment. Facilities are also available for working with hydrogen in fuels research. The parameter range over which fuel combustion research can be conducted has been greatly enhanced.

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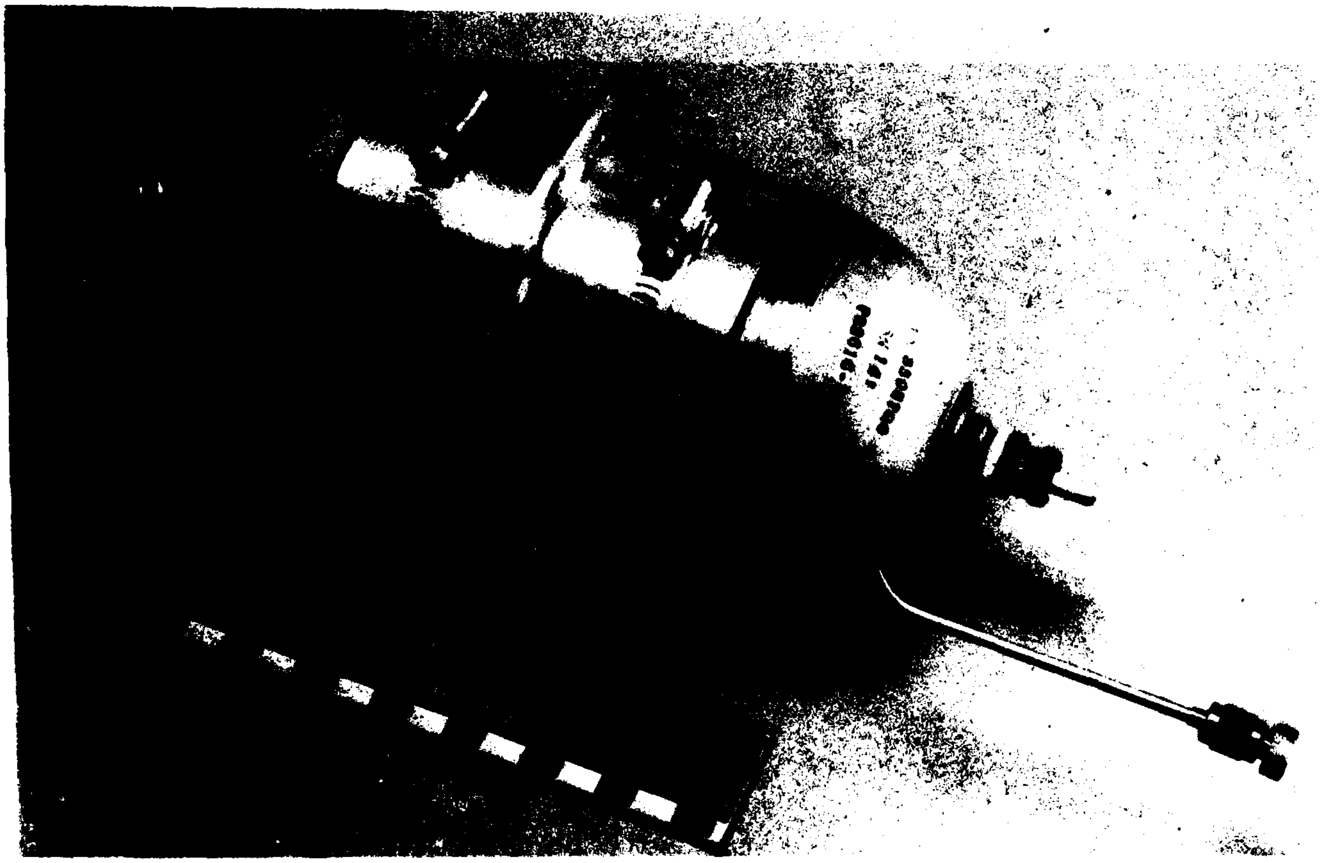
Fuels and Lubrication Laboratory

NICKEL-HYDROGEN BATTERY

An important new space battery technology developed for Air Force use will also contribute to improved communications for the 106 member nations of INTELSAT — the International Telecommunications Satellite Organization. Nickel-hydrogen battery technology, developed by the Aero Propulsion Laboratory through contracts with Hughes Aircraft Company, has been selected for use on the INTELSAT VI series of satellites. This billion dollar fleet of from 5 to 16 satellites is the largest in civil satellite history. Scheduled to begin operation in 1986, it will provide 30,000 telephone circuits and supply more than two-thirds of global communications for the rest of the 1980's. Two nickel-hydrogen batteries on each satellite will provide all on-board electrical power when the satellite's solar cells are in the Earth's shadow. Nickel-hydrogen batteries, which provide longer life and lower weight than the nickel-cadmium batteries used on most satellites, were previously selected for use on the Air Force Satellite Data System and are being evaluated for use on several other satellite systems.

Donald R. Warnock, AFWAL/POOC, 513-255-6235



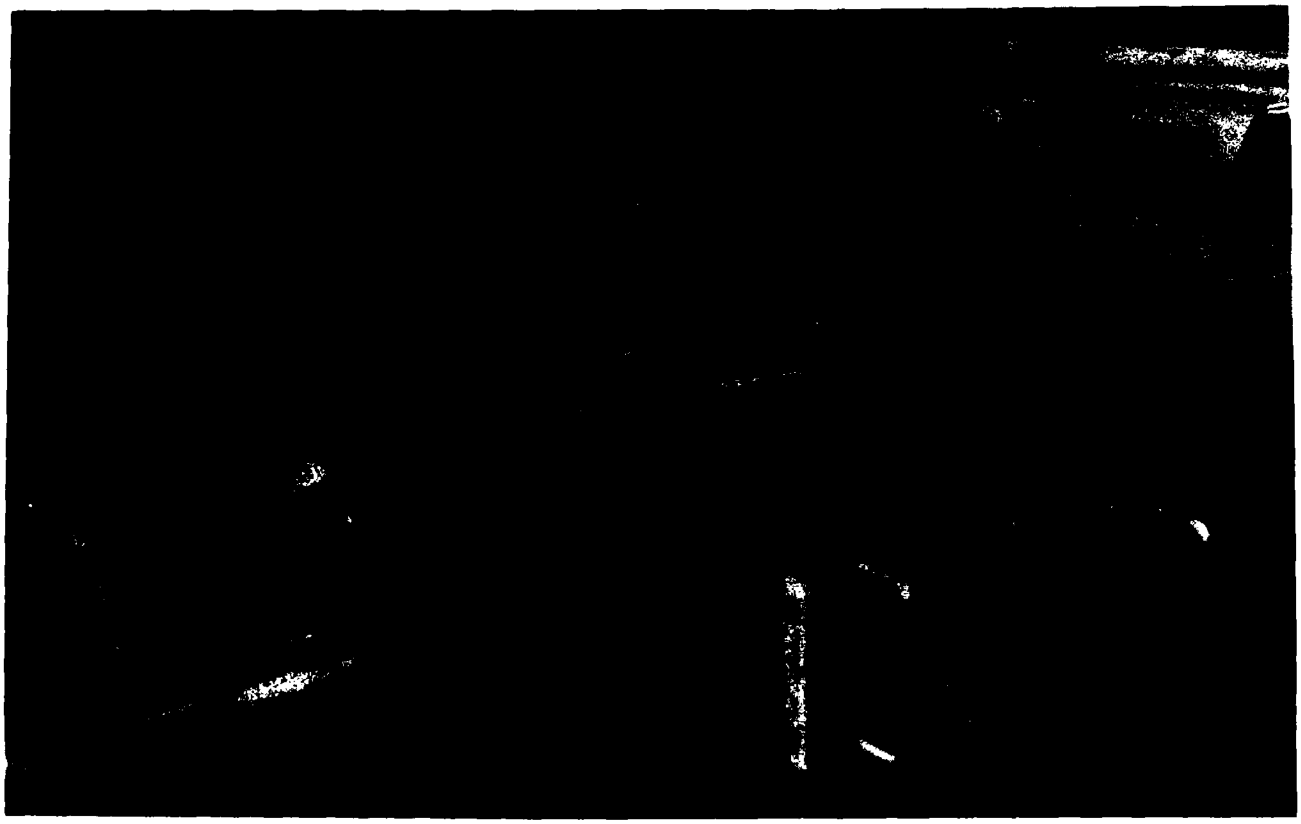
Typical Nickel-Hydrogen Battery Cell

60-KVA STARTER/GENERATOR SYSTEM

General Electric under Aero Propulsion Laboratory contract has designed and fabricated a 60 KVA permanent magnet variable speed constant frequency (VSCF) generator system. The system provides high quality, constant frequency, electrical power directly from a variable speed source without the need for a hydromechanical unit to drive the generator at a constant speed. The use of permanent magnets results in very high energy density and eliminates the magnetic structure and windings required to produce a wound field excitation.

The starter/generator system was installed on a TF-34 engine scheduled for a 500-hour accelerated cyclic endurance test at GE's Lynn engine facility. The system was used to accomplish both engine starting and electric loading during the cycle. Four hundred and thirty-four engine starts were accomplished in a period of 457 hours before the system was removed. The conventional hot gas starting system was used to complete the test and to obtain comparative test data. Results of the test indicated that, under all test conditions, the electrical start system started the engine approximately ten seconds faster than the hot gas system. The starter/generator system functioned without flaw throughout the test period. The cyclic test repre[illegible]nts approximately two years of operation on an A-10 ai[illegible] The test also verified the total compatibility betwe[illegible]he engine and starter/generator systems. The flight test [illegible] system on two A-10 aircraft at Nellis Air Force B[illegible]s scheduled for July 1983.

Paul R. Bertheaud, AFWAL/POOS, 513-255-6241



Starter/Generator System for A-10 Aircraft

HIGH POWER TECHNOLOGY DEVELOPMENTS

The feasibility of a restartable very high power gas generator using liquid oxygen and JP-4 was successfully proven. The gas generator, when used with a turbine, forms the drive section of a turbo-alternator system capable of producing tens of megawatts (MWS) of electrical power for airborne or space applications. The gas generator is approximately two feet long and ten inches in diameter.

During testing, the gas generator produced sufficient gas horsepower to drive a 15,000 horsepower turbine (11.1 MW). The generator demonstrated good temperature uniformity and combustion stability at operating conditions of 700 psi and 1500°F. The generator also demonstrated throttleability, restartability, and the capability to produce full power in considerably less than one second from start-up initiation.

During another high power technology program, the bimetallic rotor blank for a 5 MW permanent magnet generator was successfully formed using a hot isostatic pressure (HIP) bonding technique. The HIP bonding technique had been previously used on small sample devices, but had never been accomplished on a device the size of the generator rotor, 38.5 inches long and 8 inches in diameter. The rotor operating stress will be well within the bond tensile strength of 162 psi. This accomplishment is even more remarkable since the two metals are not weld compatible.

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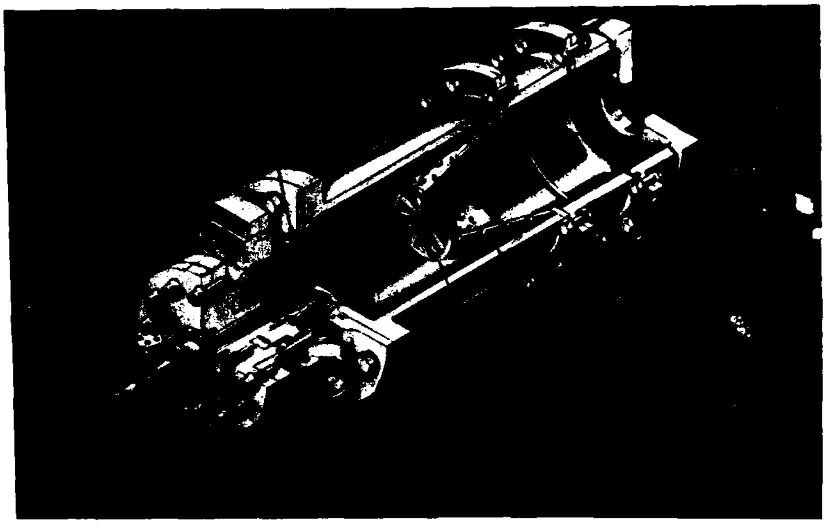
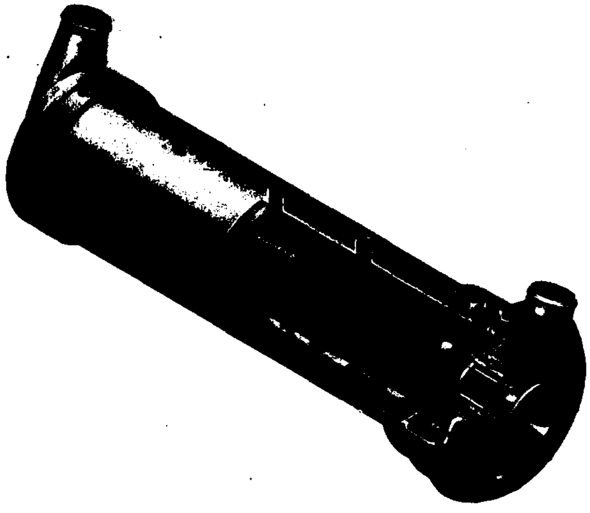


Restartable High Power Gas Generator Assembly



5 MW Permanent Magnet Generator

DUCTED ROCKET RAMJET PROPULSION

Ducted rocket ramjet propulsion offers advantages over conventional solid rocket propulsion for tractical missiles: increased range, higher average velocity, and increased maneuverability. For example, the maximum missile launch range and the range between the launching aircraft and the target at missile impact can be as much as twice the corresponding ranges for conventional rocket missiles for certain missions.

In 1982, under the Ducted Rocket Propulsion Technology Validation (DRPTV) program, propulsion system performance verification tests of a fixed flow ducted rocket in a direct-connect test facility were accomplished. Nineteen test runs were completed, including two rocket-to-ramjet transition tests. The ramburner fuel-air mixture autoignited at all ramjet takeover points and sustain operation was demonstrated over fuel equivalence ratios of about 0.5 to 3.0. Performance levels were near pretest predictions using engine cycle analysis routines; therefore, projections of flight performance capability in various missions are valid. Upon completion of the freejet test program in 1983, the ducted rocket propulsion system will be ready for flight test or full scale engineering development.

Demonstration of a variable flow ducted rocket propulsion system was also accomplished in 1982. In the direct-connect tests, fuel flow rate from the hydrocarbon gas generator was controlled with a transverse pintle valve located in the fuel duct between the gas generator and ramburner. The electrically operated valve was, in turn, controlled by a digital electronic control which compensated for time-dependent gas generator response. Desired fuel flow schedules were accurately delivered by the control. The system performed as predicted in low and mid altitude trajectories. These tests also demonstrated the possibility of operating tactical ramjets without ejecting hazardous port covers and nozzle components during rocket-to-ramjet transition. Future variable flow ducted rocket efforts will be undertaken in an effort to increase the throttle range capability and energy density by about 30 percent.

Dr. William C. Burson, AFWAL/PORA, 513-255-2175
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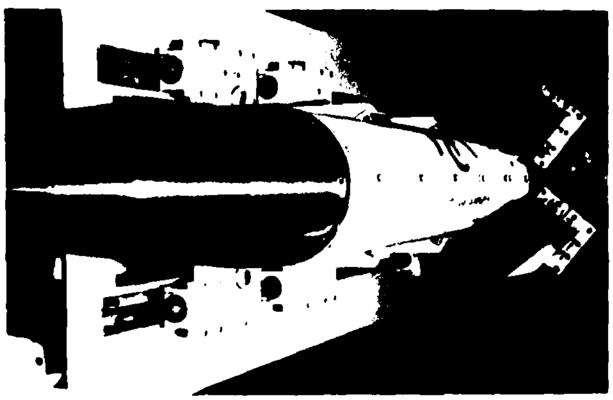
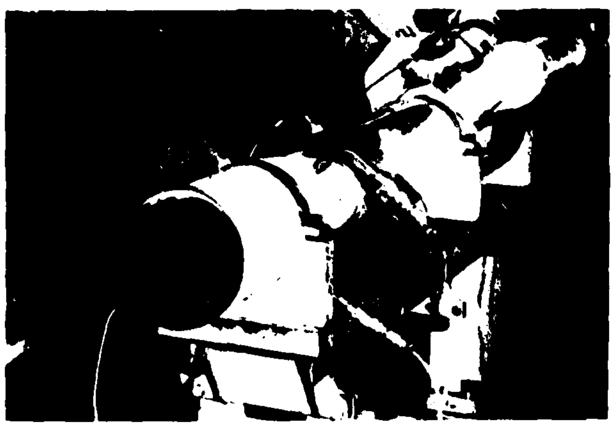


DRPTV Freejet Test Hardware

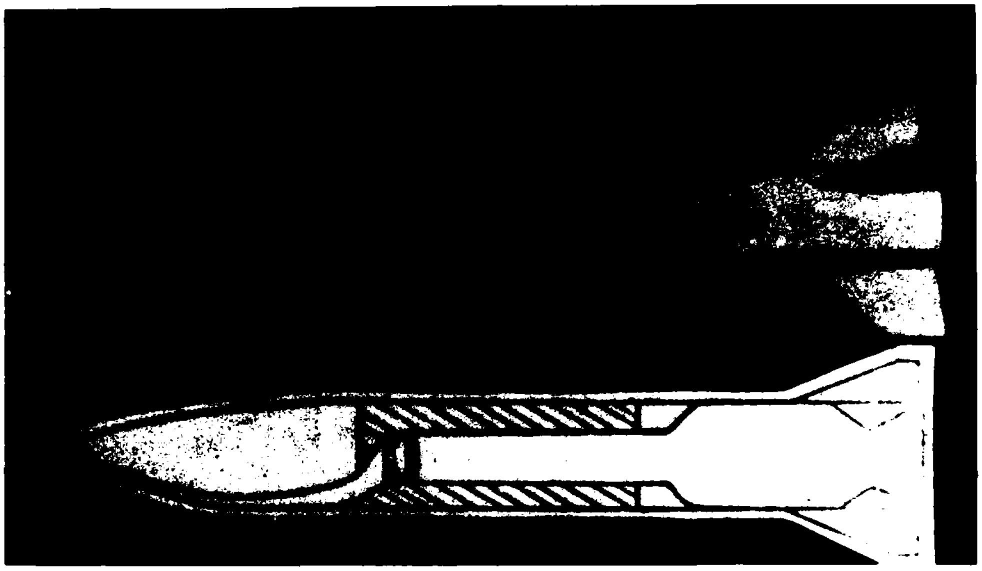


Variable Fuel Flow Ducted Rocket Ramjet Mounted on a Test Stand

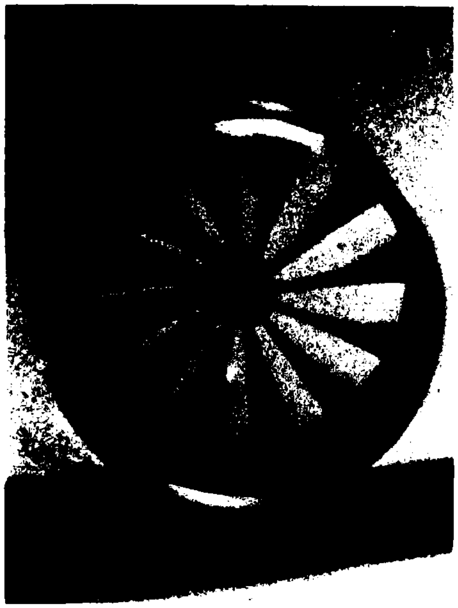
SWIRL COMBUSTORS

In-house research efforts have led to the design and evaluation of contoured swirlers which can improve both combustion efficiency and combustor total pressure loss over existing flameholder designs. By utilizing proper swirl profiles, the ramjet combustor length can be reduced to length-to-diameter ratios of less than 1.5 while still maintaining excellent combustion efficiency and avoiding the large pressure losses required by high blockage flameholders. Such swirlers have been fabricated in-house and provide . to the major ramjet engine companies who have confirmed these trends. Utilization of this new technology offers smaller, compact ramjets in applications not requiring an integral rocket booster such as the two-for-one concept for an advanced strategic missile.

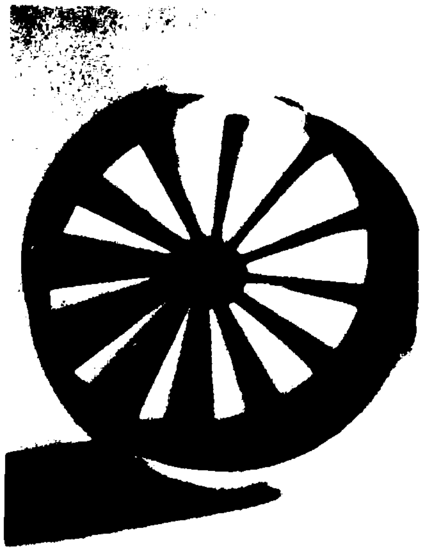
Dr. Roger R. Craig, AFWAL/PORT, 513-255-5210



Typical Applicatoin of Swirl to a Missile



Forced Vortex Swirler



Constant Angle Swirler

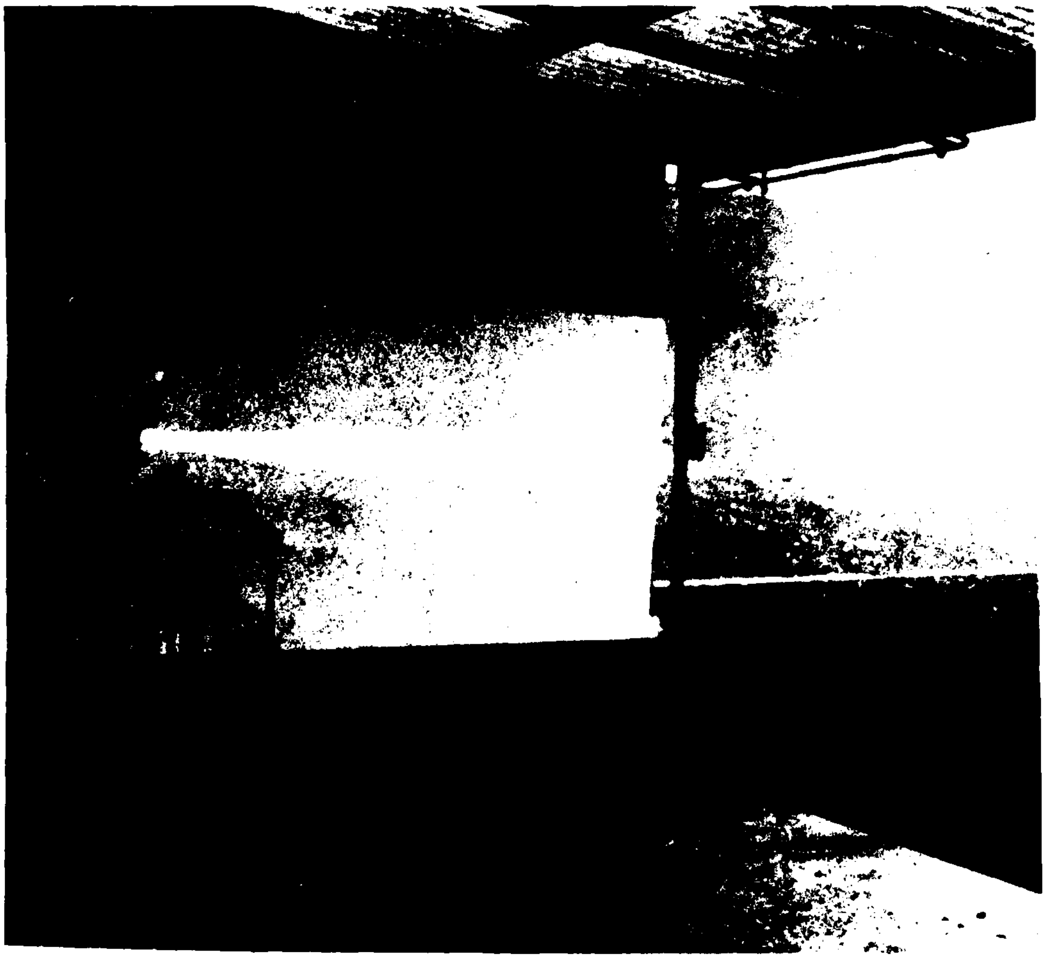
SOLID FUEL RAMJET

Impressive progress has been made in the application of castable high energy boron fuels to solid fuel ramjets (SFRJ). This fuel contains up to 70 percent intermetallic (boron) particles, by weight, has been manufactured in small-size grains, and successfully burned over a range of fuel-to-air ratios. The density is approximately 50 percent higher than that of solid hydrocarbon fuels, which when combined with an 80 percent increase in volumetric heating value, results in a significant growth potential over current solid fuels.

Direct-connect tests, performed successfully in subscale (two-inch diameter) combustors, have demonstrated combustion efficiences of 60 to 85 percent which is impressive for initial testing in small combustors. Particularly noteworthy is the fact that these efficiences were achieved with a mixer section much shorter (only two inches long) than previous mixers for hydrocarbon fuels. Combustion catalysts of titanium, aluminum, and magnesium were used, with titanium giving the best results.

A swirler insert, developed in-house for liquid fuel ramjets, was used in the air passage of a conventional solid fuel ramjet. This potential breakthrough produced excellent combustion efficiency for a circular hydrocarbon SFRJ grain without resorting to a bypass configuration. Combustion efficiency improved about 15 counts over the previous tests conducted at similar flight conditions, with only a moderate increase in pressure loss. In addition, the fuel used was left over from previous tests and showed that aging of the hydrocarbon SFRJ grains for at least five years does not adversely affect combustion performance.

Norman A. Hirsch, AFWAL/PORT, 513-255-5210



Boron Solid Fuel Ramjet Test

A-10 FUEL SYSTEM STATIC ELECTRICITY HAZARDS

In the winter of 1981, the A-10 aircraft experienced a series of fuel system fires which were suspected to be related to static electricity. As designed, the explosion suppression material (ESM) within the fuel tanks prevented the catastrophic event of an explosion; however, the residual burning caused some damage to the ESM. At the request of the A-10 System Program Office (SPO), the Aero Propulsion Laboratory assisted in the investigation of the cause and the development of corrective measures.

The in-house experiemental testing, using actual A-10 fuel system hardware, was instrumental in quickly identifying the primary cause. The two-phase fuel-air flow through the ESM generated a static charge. The spark discharge resulting from the accumulated charge could ignite the flammable vapors in the fuel tanks. The source of the static charge was associated with the survivability feature which utilized low pressure environmental conditioning system (ECS) air to purge the aerial refueling manifold of residual fuel, thus, reducing the vulnerability of the aircraft. This feature also permitted a check of the integrity of the refueling manifold and fuel shutoff valves. The release of the air into the fuel tanks however, caused the static charge and the subsequent fuel tank fire. The in-house testing also demonstrated that, even under the most severe conditions, the fuel tanks and vent system were not severely damaged by these fires.

The immediate fix was the deactivation of the air purge system until a more permanent solution could be developed. Concurrent efforts with Fairchild Republic enabled the SPO to arrive at a solution of re-routing the air purge to avoid the flow of air through the fuel.

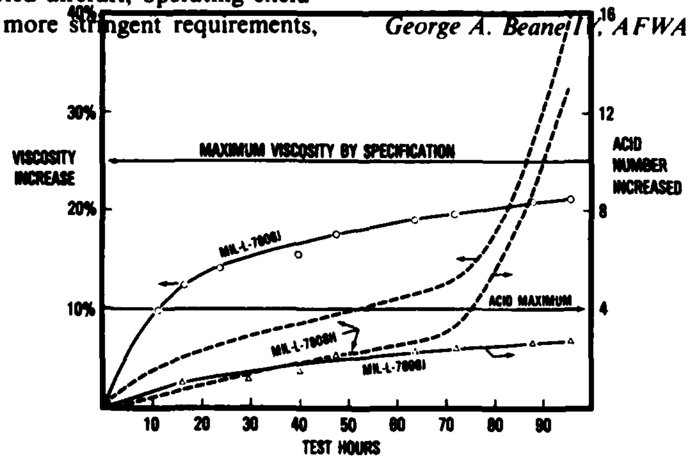
Thomas C. Hillman AFWAL/POSH, 513-255-3551

IMPROVED SYNTHETIC LUBRICANT SPECIFICATION

During the past several years, efforts within the Aero Propulsion Laboratory and industry have been directed toward upgrading the performance levels of the standard Air Force all-weather aircraft turbine engine oil specification, MIL-L-7808. This continuing effort assures the availability of satisfactory lubricants to meet the needs of advanced propulsion systems and to resolve lubricant related problems in operational engines. As a direct result of these efforts, several oils have been developed by industry which possess significantly improved thermal and oxidative stability. A "J" version of the MIL-L-7808 specification was issued in May 1982, which doubles the minimum requirements for oxidative stability. Other changes were also adopted to enhance lubricant performance and assure acceptable operation. Selected aircraft, operating exclusively on oils meeting the more stringent requirements, have demonstrated satisfactory service experience for over two years.

This effort is an example of the payoff from close cooperation between industry and Government. The Aero Propulsion Laboratory provided guidance for the improved performance standards required, while industry responded with internally funded research to develop better oils capable of meeting the increased performance requirements. The Laboratory then evaluated these oils including full scale engine endurance tests. The successful products were placed on the MIL-L-7808J Qualified Products List making them eligible for procurement by the Department of Defense.

George A. Beaney IV, AFWAL/POSL, 513-255-7463



Improved Stability of Turbine Engine Lubricants

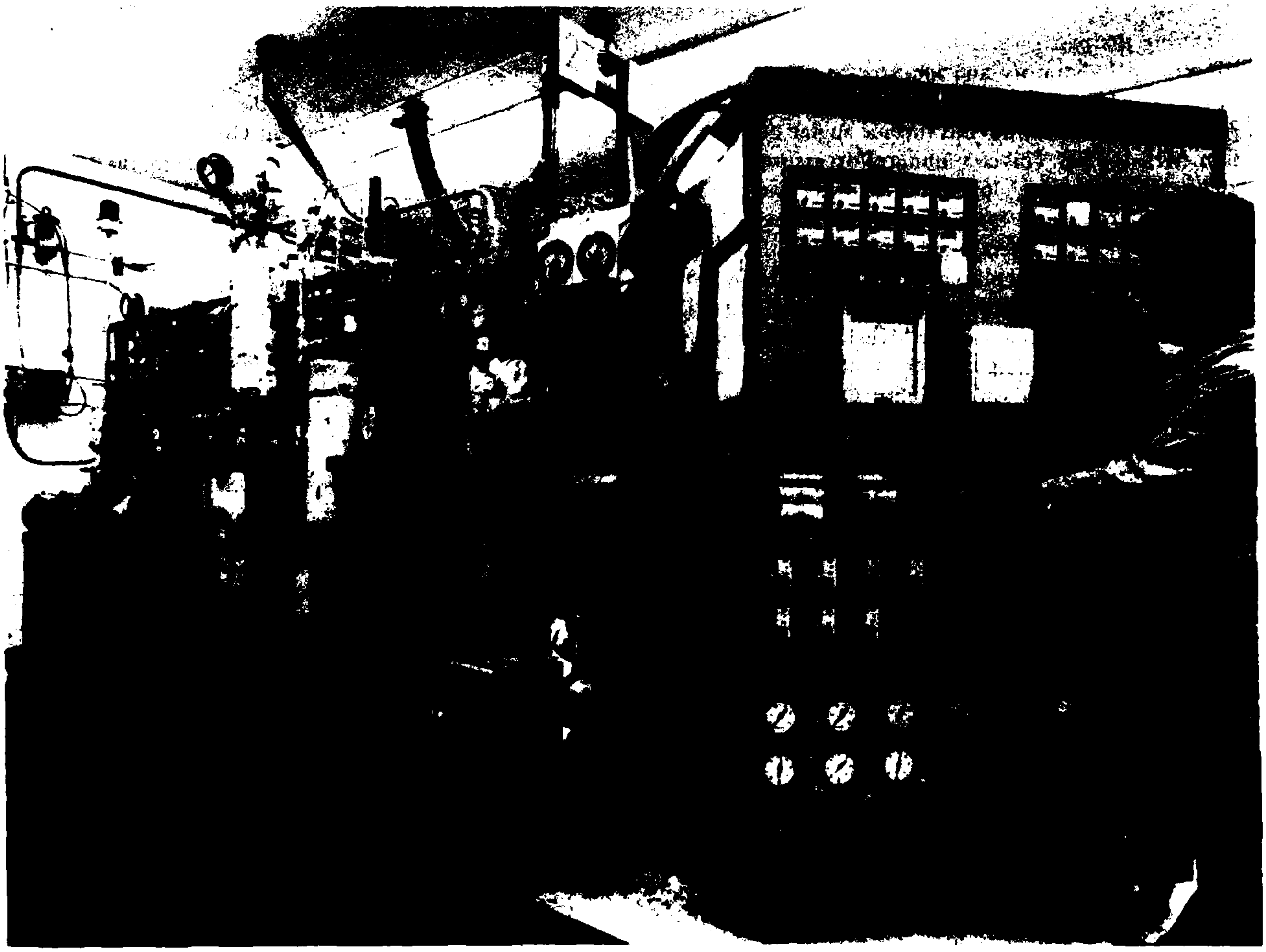
CATALYST FOR HIGH YIELDS OF JET FUEL FROM WHOLE CRUDE SHALE OIL

Upgrading shale oil into military specification turbine fuel is an expensive and complex task. The main problem results from the high levels of nitrogen present in typical crude shale oils. Nitrogen must be removed by catalytically hydrotreating the oil before it can be hydrocracked into jet fuel boiling range material.

Under sponsorship of the Aero Propulsion Laboratory, Amoco Oil Company has developed a novel catalyst capable of direct, single-stage conversion of whole shale oil into jet fuel boiling range material. The catalyst, which simultaneously hydrotreats and hydrocracks, removes virtually all of the nitrogen found in the shale oil, while maintaining very high cracking activity in the presence of elevated temperatures and high levels of ammonia. The catalyst consists of chromium, cobalt, and molybdenum oxides on a support that is half alumina and half molecular sieve. In a 100-day bench scale test, the catalyst successfully converted more than 75 percent (by weight) of an Occidental crude shale oil into JP-4 boiling range material while removing virtually all of the nitrogen from the oil. Hydrogen consumption remained a reasonable 1800-1900 standard cubic feet per barrel.

The catalyst represents a significant advance in the state of the art and contributes to refiners the capability to produce jet fuel from shale oil at costs which would be competitive with costs of jet fuel produced from petroleum sources.

Robert W. Morris, AFWAL/POSF, 513-255-6814

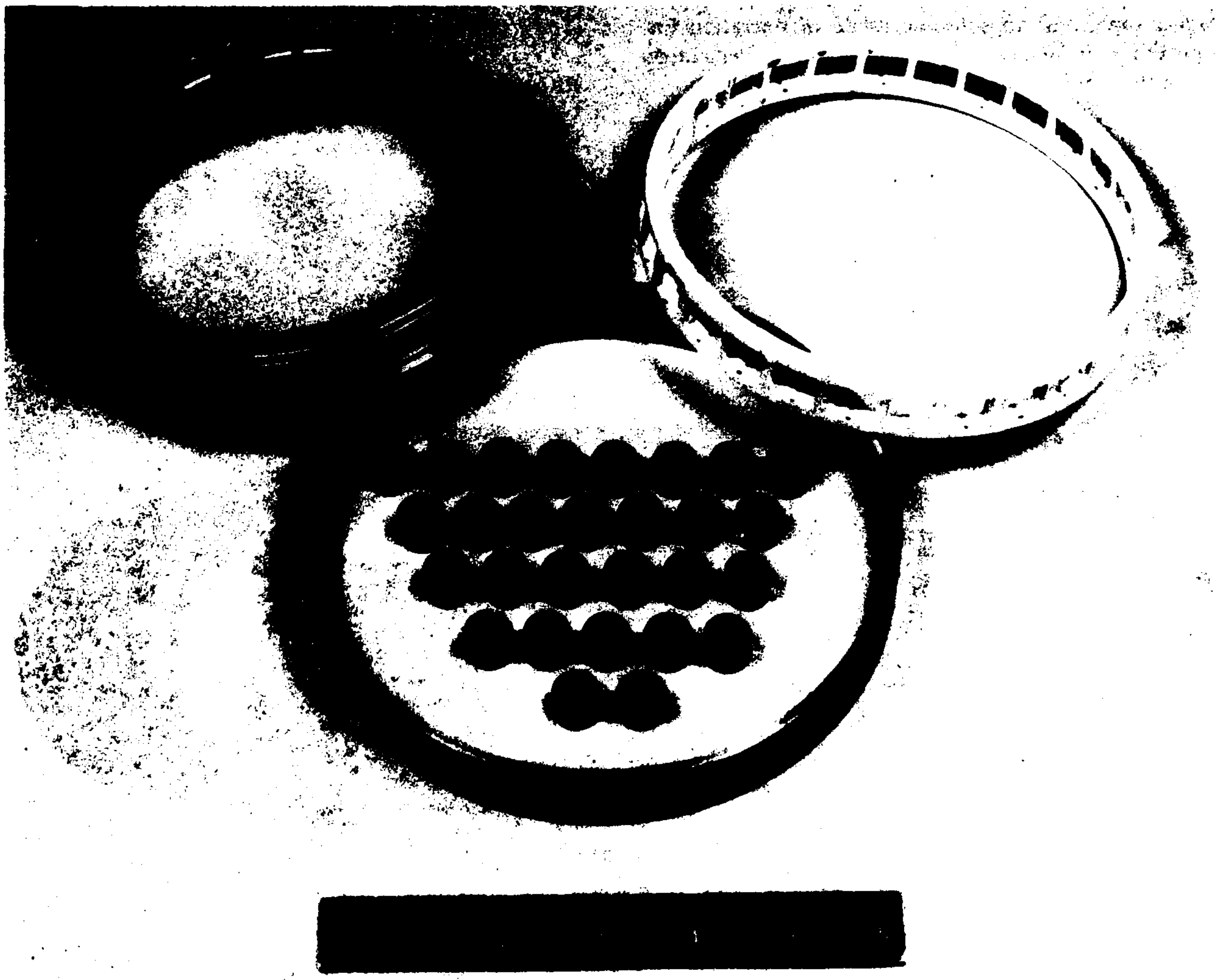


Automated Catalyst Screening Units

HIGH SPEED CYLINDRICAL ROLLER BEARING ENDURANCE CAPABILITY

The Aero Propulsion Laboratory has continued the development of high speed cylindrical roller bearings for use at speeds up to 3 million DN. The bearing bore diameter (D) in millimeters is multiplied by bearing speed (N) in revolutions per minute. Long-term operating characteristics and performance capabilities of a cylindrical roller bearing design using the analytical system developed under previous contracts have been demonstrated. A bearing with a bore diameter of 124 mm was optimized using the TRIBO I computer program, to minimize roller skew and skid at speeds up to 3.0 MDN. This bearing was evaluated for wear and durability in a 1000-hour endurance test. The test was run for 250 hours at 2.5 MDN, 250 hours at 2.75 MDN, 500 hours at 3.0 MDN and 50 hours of acceleration/deceleration between 1.8 and 2.9 MDN. Bearing load was maintained at 500 pounds. As far as is known, this testing represents the longest sustained operation of cylindrical roller bearings at these operating conditions. Inspection of the test bearing following the 1000-hour endurance test showed no significant bearing wear as measured by changes in roller weight, roller skew angle, or in roller balance. The bearing appeared to be in excellent condition and capable of continued operation.

John B. Schrand, AFWAL/POSL, 513-255-7477



0.87 L/D Roller Bearing S/N4 Successfully Completed 1000 Hour Endurance Test

GE23 JOINT TECHNOLOGY DEMONSTRATOR ENGINE

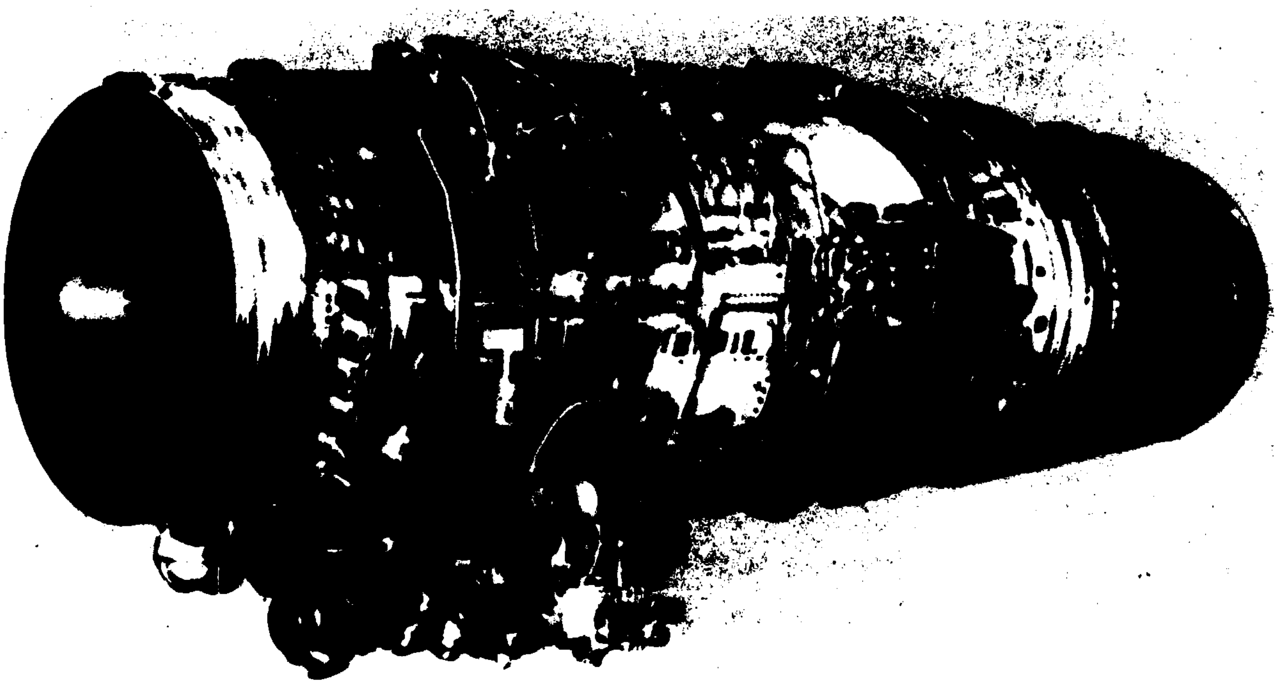
The GE23 Joint Air Force/Navy Technology Demonstrator Engine (JTDE) is a result of five years of cooperation between the Aero Propulsion Laboratory and the Navy Air Propulsion Center, Trenton NJ. The primary objective of this program was to evaluate advanced variable cycle engine technology and configurations capable of changing their internal component geometry (and performance) to respond to changing air speeds and altitudes.

The GE23 JTDE variable cycle configuration was achieved by integrating advanced low-pressure spool components, such as a split fan concept and a variable single-stage turbine, advanced materials, variable fan stream grometry, and an electronic engine control system with an advanced reliable gas generator. Variable geometry features in the fan stream are used to convert the GE23 JTDE from a supersonic to subsonic mode of operation for improved performance and fuel consumption over a large part of the flight envelope.

In January 1982, initial altitude performance, stall, and cyclic durability tests of the GE23 JTDE were completed with outstanding results. Performance testing was conducted at a maximum altitude of 45,000 feet and Mach numbers up to 1.3. Over 30 fan stalls were conducted and the engine was operated through approximately 350 idle-intermediate-idle cycles and 110 cruise-intermediate-cruise cycles. During this testing, the engine logged 123 hours and 47 minutes of failure-free operation of all major components.

The JTDE's advanced designs and materials point to an engine of the 1980's and 1990's with increased durability, lower parts count, and lower fuel consumption. This will be achieved at a reduced life cycle cost while maintaining the required improved performance standards.

Richard G. McNally, AFWAL/POTP, 513-255-2278



GE 23/F1A1 Engine

VECTORING/REVERSING NOZZLE TEST

An F100 engine with a two-dimensional/convergent/divergent exhaust nozzle demonstrated thrust vectoring and reversing capability. The nozzle can operate in reverse from idle-to-intermediate power and in vectored mode from idle-to-maximum augmentation, as well as any combination of reversing and vectoring.

The tests, sponsored by the Aero Propulsion Laboratory, included steady state and transient engine and nozzle operation with various combinations of reversing and vectoring. Measured thrust in the forward mode was the same as with the F100 production nozzle; vectoring forces were as predicted for all angles and reverse thrust was measured to be 50 percent or more of forward thrust for all power settings. The nozzle translates from the forward mode to full reverse or full vectoring (±20 degrees) in less than one second, and stable engine operation was maintained during all transients.

Studies have shown that vectoring/reversing nozzles can reduce takeoff and landing distances for operation on bomb-damaged runways. Landing distances for typical tactical aircraft can be reduced to approximately 1200 feet, for operation on dry, wet or icy runways. Takeoff distances can also be reduced. Vectoring can also be used to aid in maneuvering and trimming the aircraft. The addition of reversing/vectoring capability adds weight to the nozzle, but studies indicate that this weight increment can be offset by reduced control surface and/or speed brake area. The nozzle configuration can be tailored for each installation to best meet that aircraft's needs.

Ronald J. Glidewell, AFWAL/POTC, 513-255-2367

UP-VECTOR

HORIZONTAL

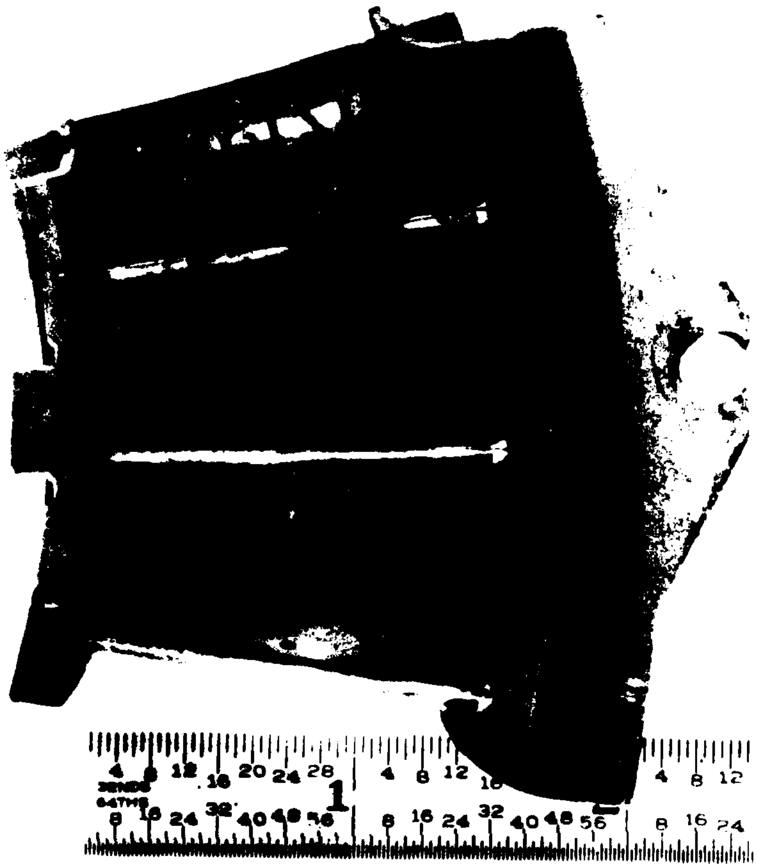
DOWN-VECTOR

MEASUREMENT AND ANALYSIS OF HEAT-FLUX DATA IN A TURBINE STAGE

Extensive quantities of turbine airfoil heat transfer data were obtained using a shock tunnel as a source of heated, high-pressure air. Miniature thin-film heat-flux gages were employed to obtain high-quality, point-resolution measurements in a full high-pressure turbine of the Garrett TFE 731-2 turbofan engine. The data were taken over a range of realistic turbine operating conditions and subsequently compared to predictions made by both simple integral and advanced transitioning finite-difference boundary layer codes. The results showed the range of applicability of the various heat transfer predictive codes and served to illuminate the need for reassessing boundary layer transition criteria.

This activity constitutes a major milestone in that it is the first time such extensive quantities of high-quality heat transfer data were obtained for real engine turbine hardware operating under realistic engine conditions. Further, the turbine test conditions, blade and vane coordinates, and body of heat-flux data, when taken together, constitute a concise, yet complete, reference source for validating boundary layer predictive codes. Given the importance of proper heat transer and cooling design in turbines, the Air Force will benefit by knowing qualitatively and quantitatively industry's strengths and weaknesses in this technology area. This information will allow for more effective Air Force program planning in the turbine heat transfer and cooling research and development field.

Lt. Jeffrey L. Holt, AFWAL/POTC, 513-255-3150

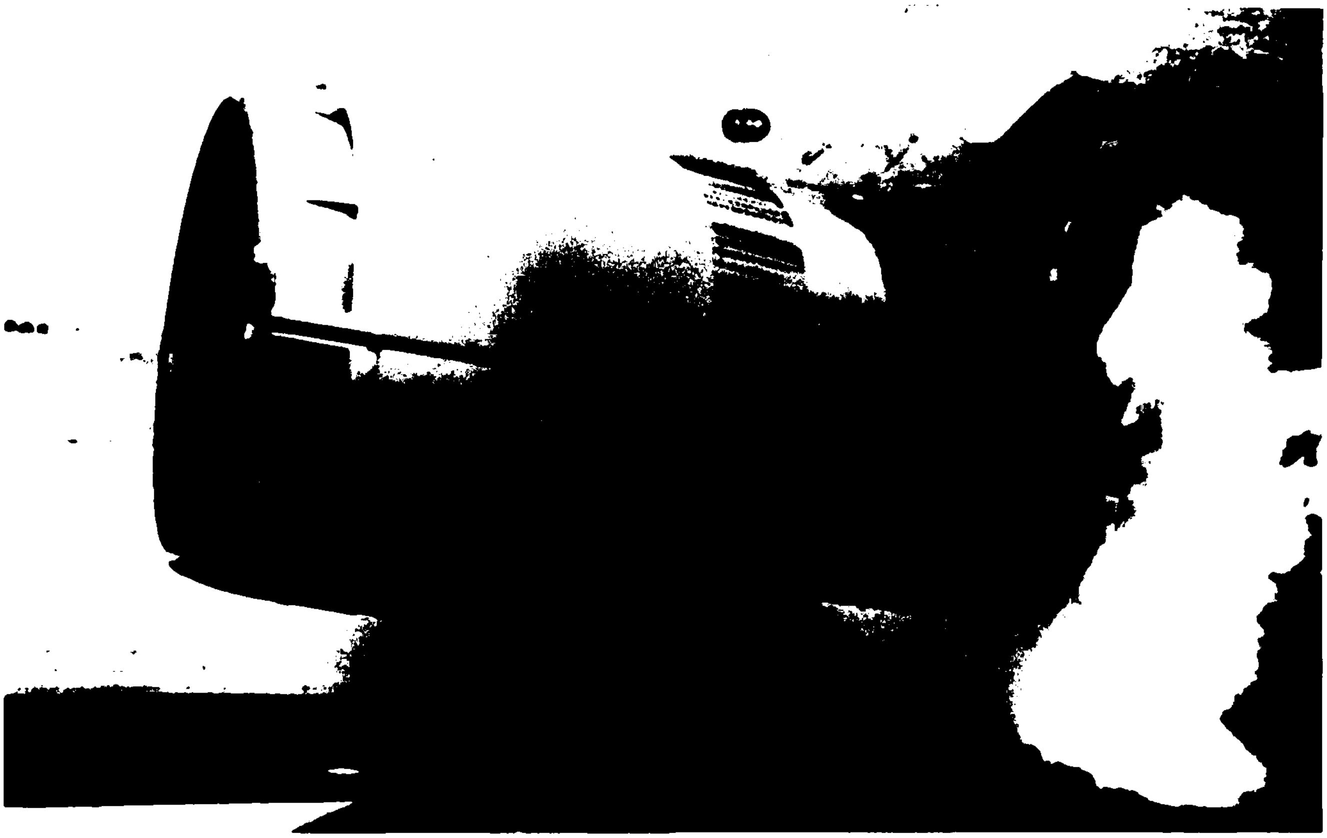


Placement of Miniature Thin Film Heat Flux Gauges

ADVANCEMENTS IN COMPRESSION SYSTEM OPERATIONAL STABILITY

Stall-stagnation of an engine happens when an event such as a hard afterburner ignition, a heavy inlet distortion, etc., occurs and destabilizes to near-idle or sub-idle levels and the turbine inlet temperature rises. The engine will not repond to throttle lever movements; hence, a "stagnated" condition exists. The engine must, therefore, be shut down and a restart accomplished to clear the stagnation condition. F100 and F101 engines instrumented with 100-200 channels of high-frequency, high-response pressure gages were tested at AEDC. These engines were intentionally stalled and driven into a stall-stagnation condition. The resulting high-frequency data, taken during the onset of each stall-stagnation event, was recorded. Fast Fourier Transform analysis of these data allowed frequency and time data correlation of all recorded channels simultaneously, a major advancement in the reduction and analysis of multi-channel, high-response data of this type. This analysis technique permitted events and associated phenomena to be isolated and identified, and engineering judgments exercised as to cause and effect. Using this analysis technique, a major advancement toward the understanding of nonrecoverable stall was made: rotating stall need not be a precursor to a stall-stagnation event as previously theorized. These test data are now being used to validate nonrecoverable stall prediction models, engineering tools which will become valuable additions to the compressor design criteria. The ultimate goal is to provide an upgraded design procedure which will assure stall-free performance of future compression systems at all operating conditions.

Harry R. Bankhead, AFWAL/POTA, 513-255-2121



Compressor Stall

SECTION II
AVIONICS LABORATORY

VHSIC MACROCELL DESIGN LIBRARY

The Very High Speed Integrated Circuit (VHSIC) program being conducted by the Avionics Laboratory has achieved a major milestone with the design of a set of basic integrated circuit building blocks called macrocells. This set of basic macrocells can be used for a variety of digital signal processing functions. They can be combined into full scale VHSIC integrated circuit chips, which have specific functions such as radio communications, navigation, radar signal processing, and computer control. Using VHSIC technology, these chips will operate three to four times faster, occupy 1/10 to 1/100 of the volume, and weigh less than 1/10 as much as current integrated circuits performing the same functions.

Macrocell test chips are fabricated and tested to prove the operational feasibility of the designs before they are incorporated into full scale VHSIC chips. Each VHSIC contractor designed full scale chips based on combinations of these macrocells so that specific brassboard system demonstrations can be accomplished. Computer Aided Design (CAD) facilities have been established at each contractor's plant to enable the use of the macrocells for rapid turn around on the design of future VHSIC chips not included in the present VHSIC program. A "computer library" of the designs now exists for use as needed in developing future chips. In addition, the designs, software, and data are owned by the Department of Defense, and therefore can be provided to all suppliers.

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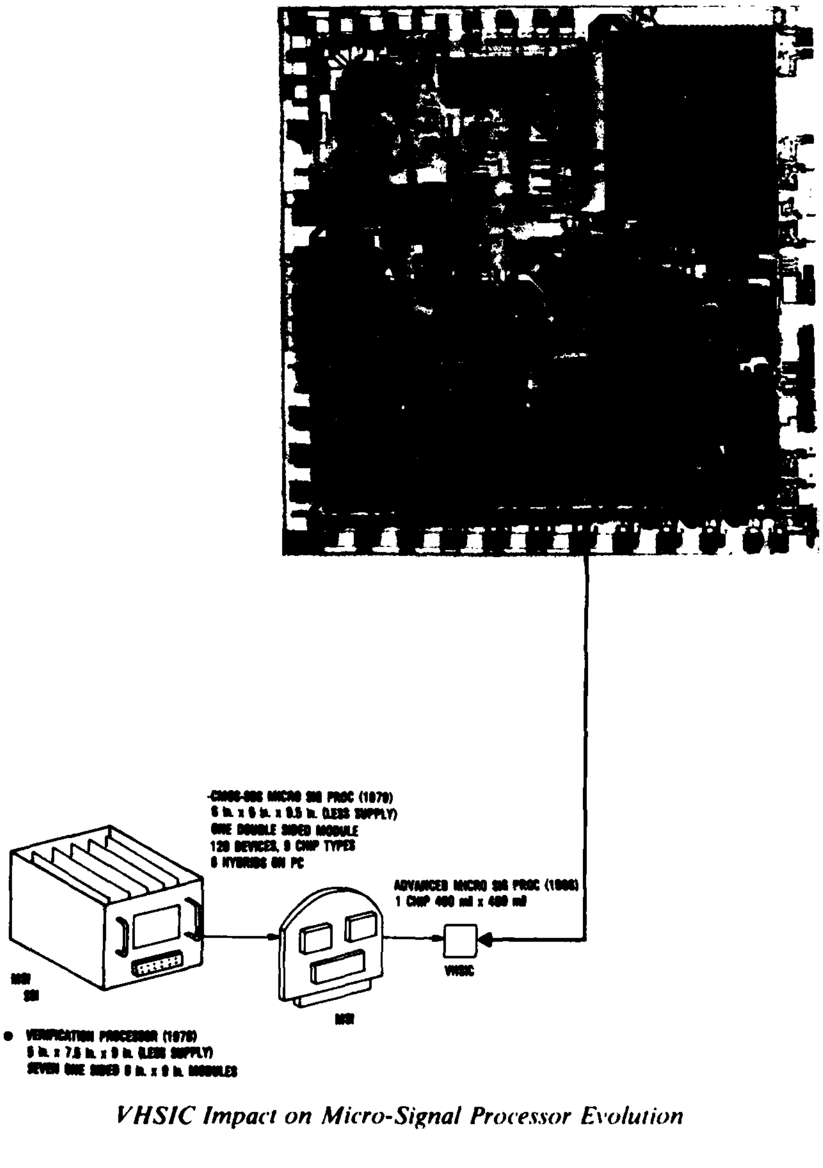

VHSIC Impact on Micro-Signal Processor Evolution

EW RECEIVER SENSITIVITY STUDY

Electronic warfare receiver development is being carried on at the Avionics Laboratory. Such receivers intercept hostile electromagnetic radar signals and pass the appropriate information to processing systems where assessments are made of possible missile threats to an aircraft. Figure 1 shows a fundamental radar detection receiver block diagram consisting of an RF filter, a detector, a Video filter, and a threshold comparator. The RF filter determines the part of the RF spectrum received; the detector strips the RF carrier from the signal and passes the radar pulse envelope; and the threshold comparator compares the video signal amplitude voltage to a predetermined voltage level.

Too low a threshold means the receiver will have a high probability of detecting the radar pulse (Pd), but will also have a high probability of mistaking noise pulses for a radar pulse, which is called a false alarm (PFA). Too high a threshold means the receiver may not be sensitive enough; the probability of false alarm (PFA) will be low but the probability of detection (Pd) will also be low. Determining the Pd for a given PFA and relating the Pd to receiver sensitivity has been a difficult research area because theoretical results have not compared well with laboratory and field test data.

Previous work determining Pd and PFA was based on receiver designs having approximately equal RF and Video bandwidths (BR=BV). In reality, this type of design applies only to a very small class of EW receivers. Calculation and theory involved for determining Pd and PFA as a function of signal-to-noise (S/N) ratios for such a receiver is well developed. However, since the EW receivers should view as wide an RF bandwidth as practical, they are usually designed with large BR to BV ratios and well developed theory does not apply. Laboratory work determined the theoretical effect of different bandwidth ratios on Pd and PFA. Figure 2 shows it is possible to obtain a high Pd even with negative S/N ratios. By correctly interpreting the existing theory and applying the curves of Figure 2, calculations can be made on receiver sensitivity which compare extremely well with laboratory data. This in-house work has established correlation between theoretical and measured values of Pd and PFA. A specific technique establishing EW receiver sensitivity using Pd and PFA calculations has now been developed. The technique has established standards for EW receiver sensitivity calculations.

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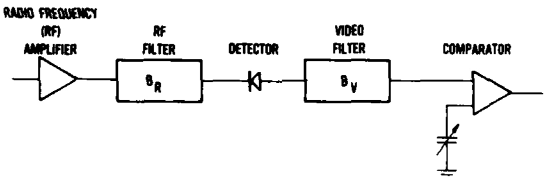

(A) CONVENTIONAL RECEIVERS $B_R = B_V$
(B) EW RECEIVERS $B_R >> B_V$

FIGURE 1. A SIMPLIFIED RECEIVER DIAGRAM

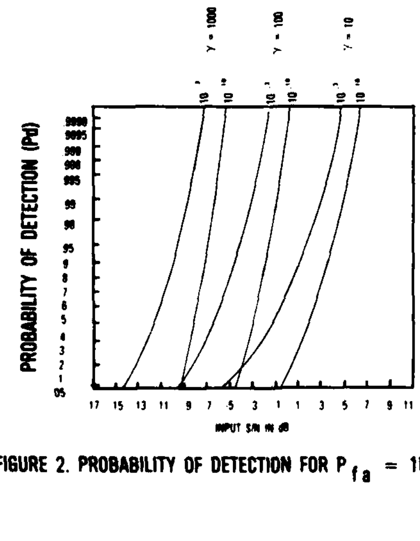

FIGURE 2. PROBABILITY OF DETECTION FOR $P_{fa} = 10^{-3}$ and 10^{-10}

ADVANCED FLARE

Existing Infrared (IR) decoy flares are either rectangular or cylindrical in shape and are simply ejected from the aircraft dispenser at a predetermined ejection velocity. The advanced flare is designed to be ejected from these same dispensers, but is aerodynamically configured with foldout fins to provide a controlled trajectory with respect to the aircraft. The flares can use either solid or liquid pyrotechnic compositions. Particularly important are the location of the center of gravity, controlled stability, and the composition of the pyrotechnic. Evaluation was accomplished in a simulated dynamic environment which included pressure, temperature, and windstream effects. Units were systematically evaluated via laboratory tests, high speed ejection at ground level, and actual airborne tests. The airborne tests used dedicated measurement and evaluation pods which included tracking by IR homing missile seekers. This particular design includes a shroud extension to provide better fuel and air mixing for improved radiation control and efficiency.

Significantly, the use of this flare provides a controlled separation trajectory for the IR decoy, while still using existing aircraft dispensers. The flare has a combustion chamber to provide overall controlled stability and thrust and controlled radiation output can be obtained using either solid or liquid pyrotechnics. The design is cost effective compared to current flares, and has demonstrated good reliability, repeatability, and maintainability. In the solid pyrotechnic configuration, use of the overall unit (all components) for several years has demonstrated that a long shelf life is possible.

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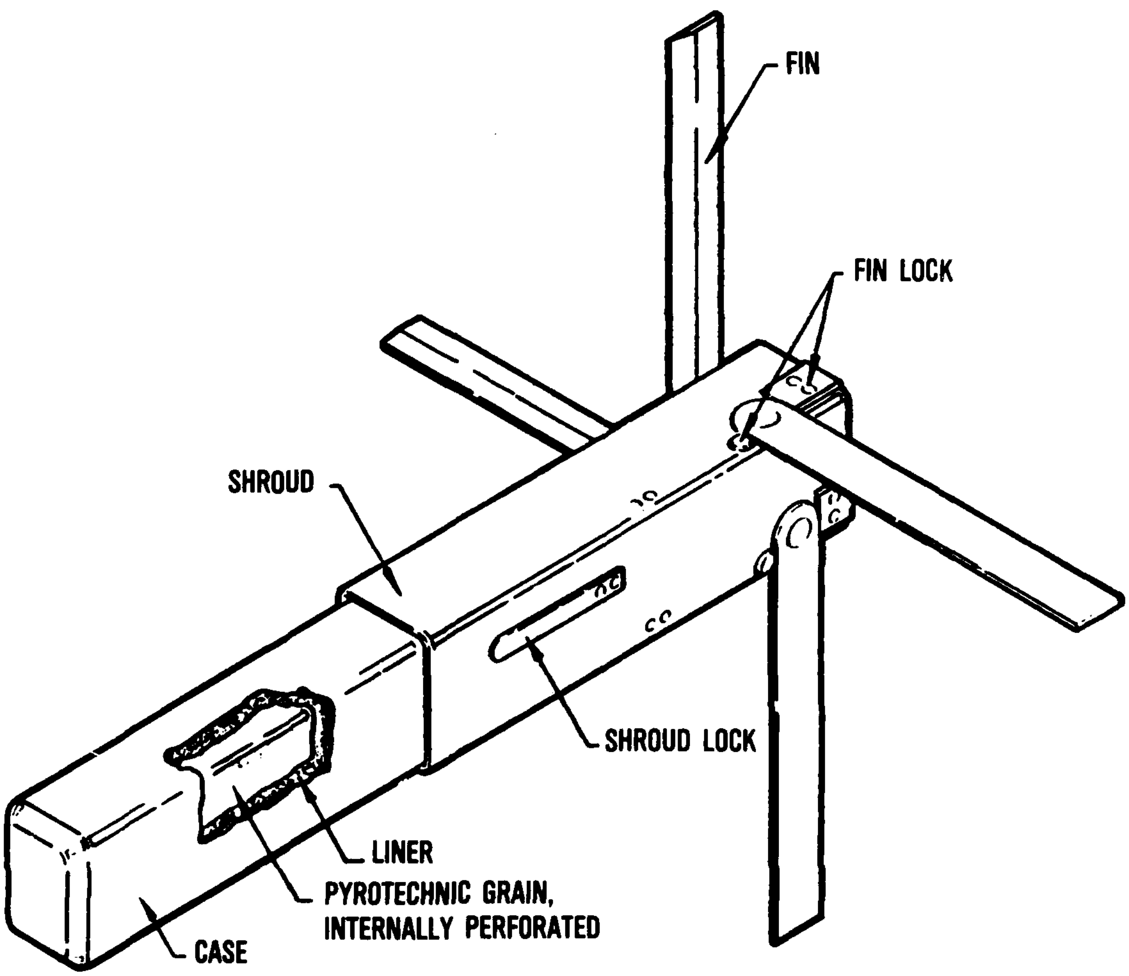

Pyrotechnic Advanced Flare Assembly

ADVANCED ECM TRANSMITTER

Acceptance testing of the advanced transmitter flyable brassboard was completed at Sedco Systems Inc. This transmitter system was a joint USAF NAVY program managed by the Avionics Laboratory and directly supported by the Naval Air Systems Command. The objective of the program was to develop and flight test an AN ALQ-99 band 9 10 transmitter assembly. The potential application is to tactical support jamming as provided by the USAF EF-111A and USN EA-6B aircraft. The new brassboard, configured for flight testing in a modified AN ALQ-99 pod on a Navy A-3 test aircraft, provided increased frequency coverage, high effective radiated power (ERP), and multiple simultaneous beams against a broad class of threat systems. The acceptance tests included: operation of a dual traveling wave tube (TWT) amplifier chain across the entire band 9 10 frequency; frequency set-on; measurement by the control panel threat simulator; beam switching at required speeds; and tracking jamming of three simultaneous threats over a ± 45 degree azimuth sector from a single planar array aperture.

The advanced transmitter brassboard demonstrates that technology is now available to apply planar phased array antennas with multiple simultaneous durable beams to provide effective pulse jamming cover against acquisition and/or tracking radars. Because multiple phased-matched continuous wave TWT amplifier pairs with octave plus band width are employed with high gain arrays, 10 to 15 db higher power (single beam) can be provided by existing ECM systems using these retrofitted transmiters. No increase in required prime power or hardware size result from this hardware, but there is a minor weight impact.

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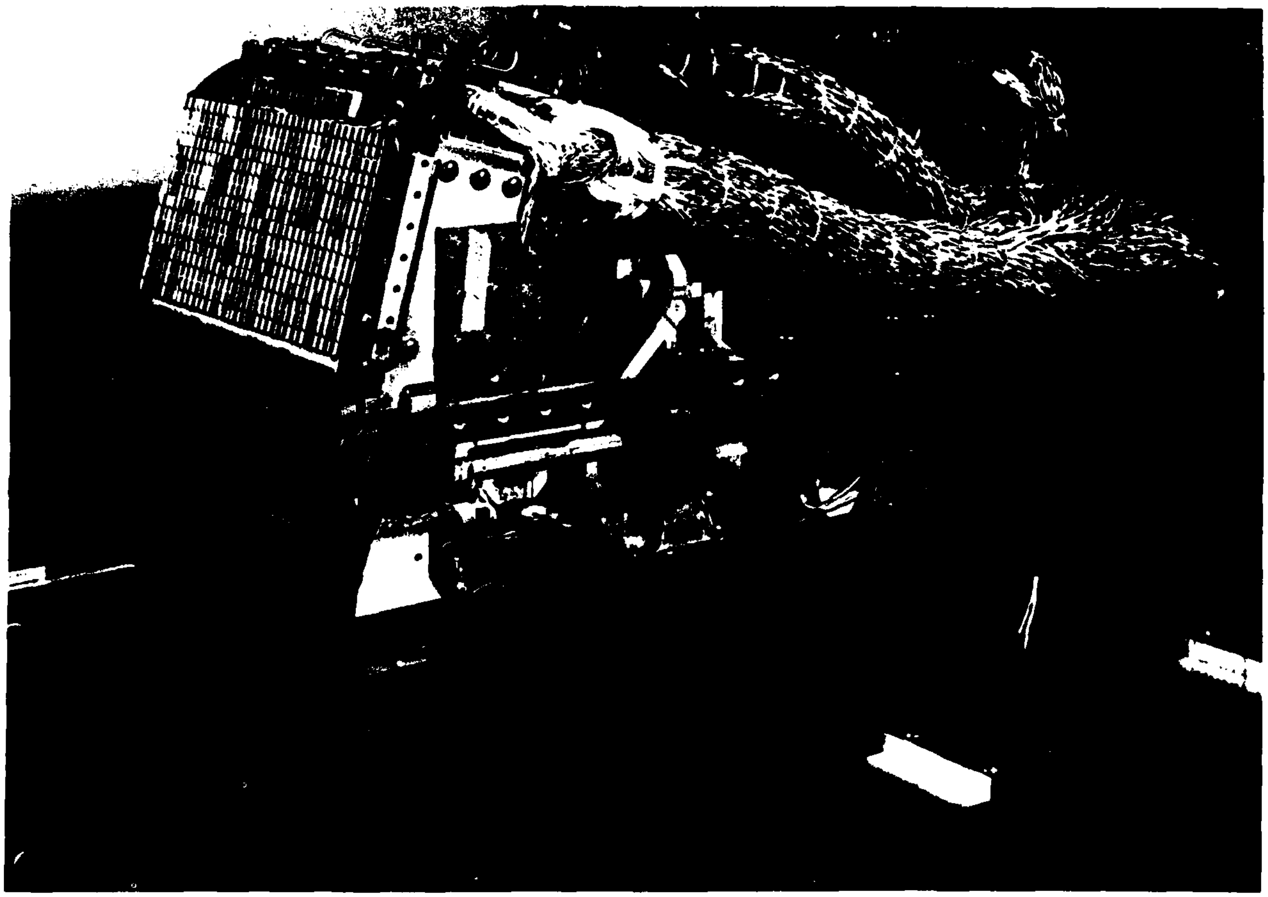


Advanced Transmitter ALQ-99 Band 9/10 for EF-111A TJS

AIR-TO-AIR ELECTRONIC COUNTER-COUNTERMEASURES PROTECTION

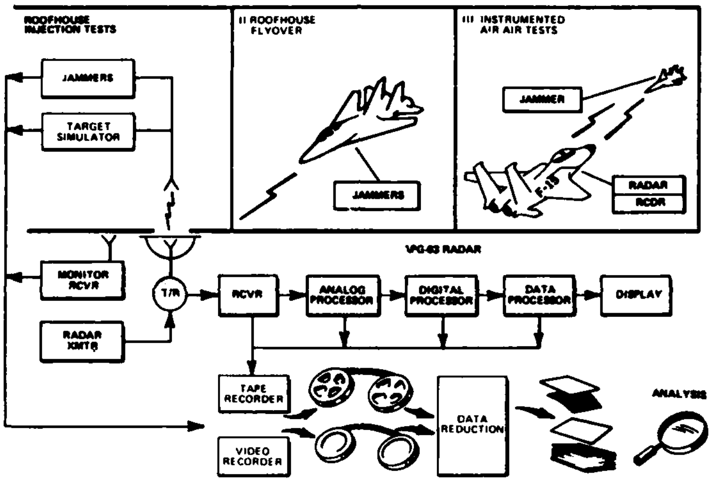
Airborne radar systems can be susceptible to electronic countermeasure (ECM) jamming. This type of interference can result in much degraded radar effectiveness and decreased fighter and bomber aircraft survival.

Under an Avionics Laboratory program, the detailed effects of various ECM signals on an airborne intercept radar system were obtained and analyzed. This was the first time that specific, detailed, and quantitative engineering test data of these effects have been obtained. Previous test data have been of a very qualitative nature, resulting in incomplete or misleading information. A modern radar system, the F-15's AN/APG-63, was extensively instrumented and tested to ensure applicability of the test data to current systems and to provide data for future radar system designs.

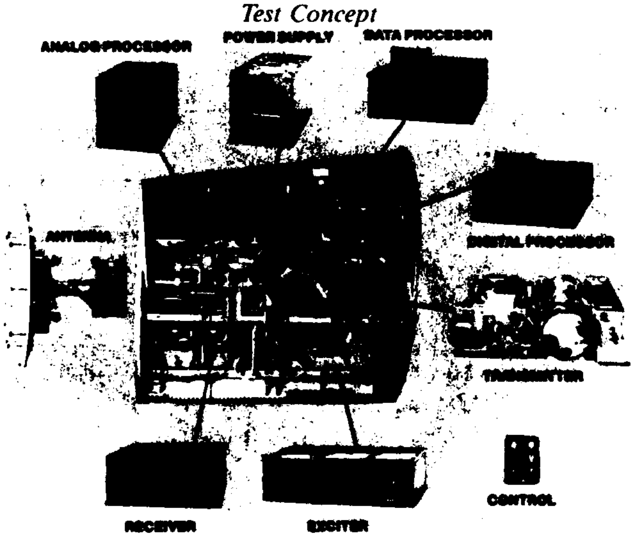
The data were provided to the F-15 System Programs Office, which used the information to develop engineering design changes that will enhance the electronic counter-countermeasures (ECCM) protection of the APG-63 system. The information can also be used to increase the ECCM characteristics of other current airborne radar systems or the design of future radar systems. The end result of this program will be increased aircraft protection from radar jamming and therefore, significantly increased mission effectiveness and aircraft survivability.

Richard L. Mercer, AFWAL/AARM, 513-255-3006

TEST CONCEPT



Test Concept

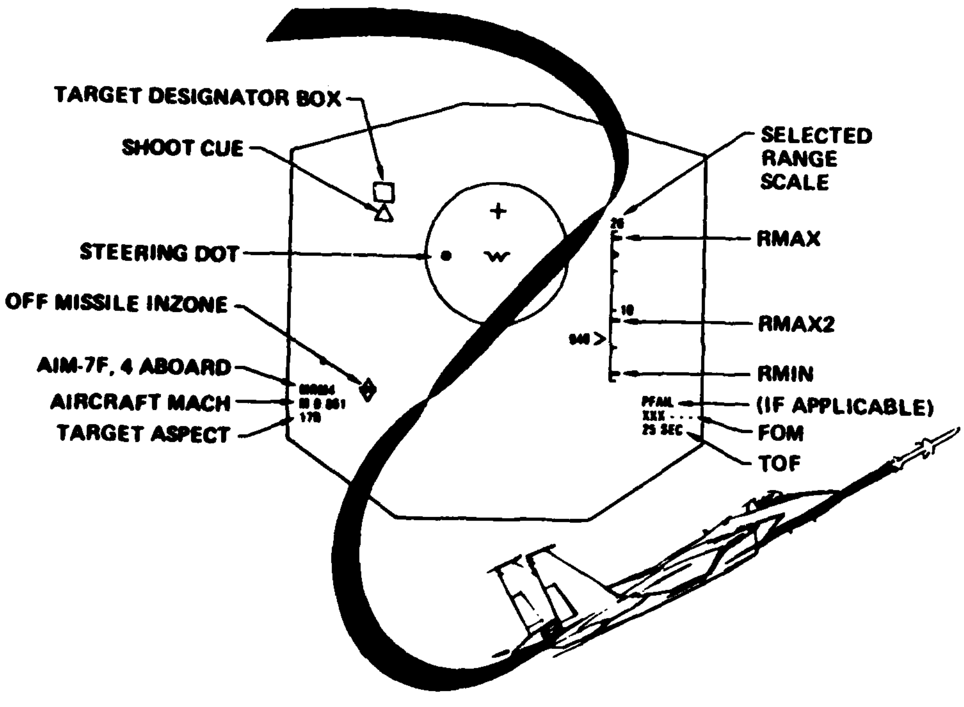


AN/AP6-63 Radar

ADVANCED MISSILE LAUNCH ENVELOP ALGORITHM

The Avionics Laboratory has recently completed the development of significantly improved missile launch envelope (MLE) algorithms. These algorithms result in improved air-to-air combat performance of USAF fighters. Goals of the program were to decrease the number of bad and missed opportunity shots, give the pilot better pre-launch data, generate accurate missile time-to-impact, and predict failure due to target maneuver after launch. Current MLE algorithms provide maximum and minimum launch ranges for non-maneuvering air-to-air targets only. The new MLE algorithms show an improved accuracy of 25-500 percent over current algorithms for maximum range computations. The lower percentage improvement is for co-altitude launches against a non-maneuvering target and the higher percentage occurs for look-up or look-down engagements where current algorithms have little capability. The new MLE algorithms offer range indications, time to maximum range when outside the MLE, missile flight time, and target maneuvers needed to defeat the attack missile. Post-launch cues include accurate missile flight time and predicted missile failure, both updated by actual target track data. Post-launch cues are important in a multiple target situation for the pilot to support an in-flight missile, press in for re-attack, or disengage for a more lucrative target. The modular nature of the new algorithms allows for versatility in accepting new air-to-air missiles or updated versions of current missiles. Accurate engagement trend data cues have improved pilot ability to manage a tactical engagement and relaunch capability, and have increased kill probability. Some improved MLE algorithms and displays have already been incorporated into the F-15 and F-16 with enthusiastic pilot response.

Capt. David E. Chaffin, AFWAL/AART, 513-255-3215



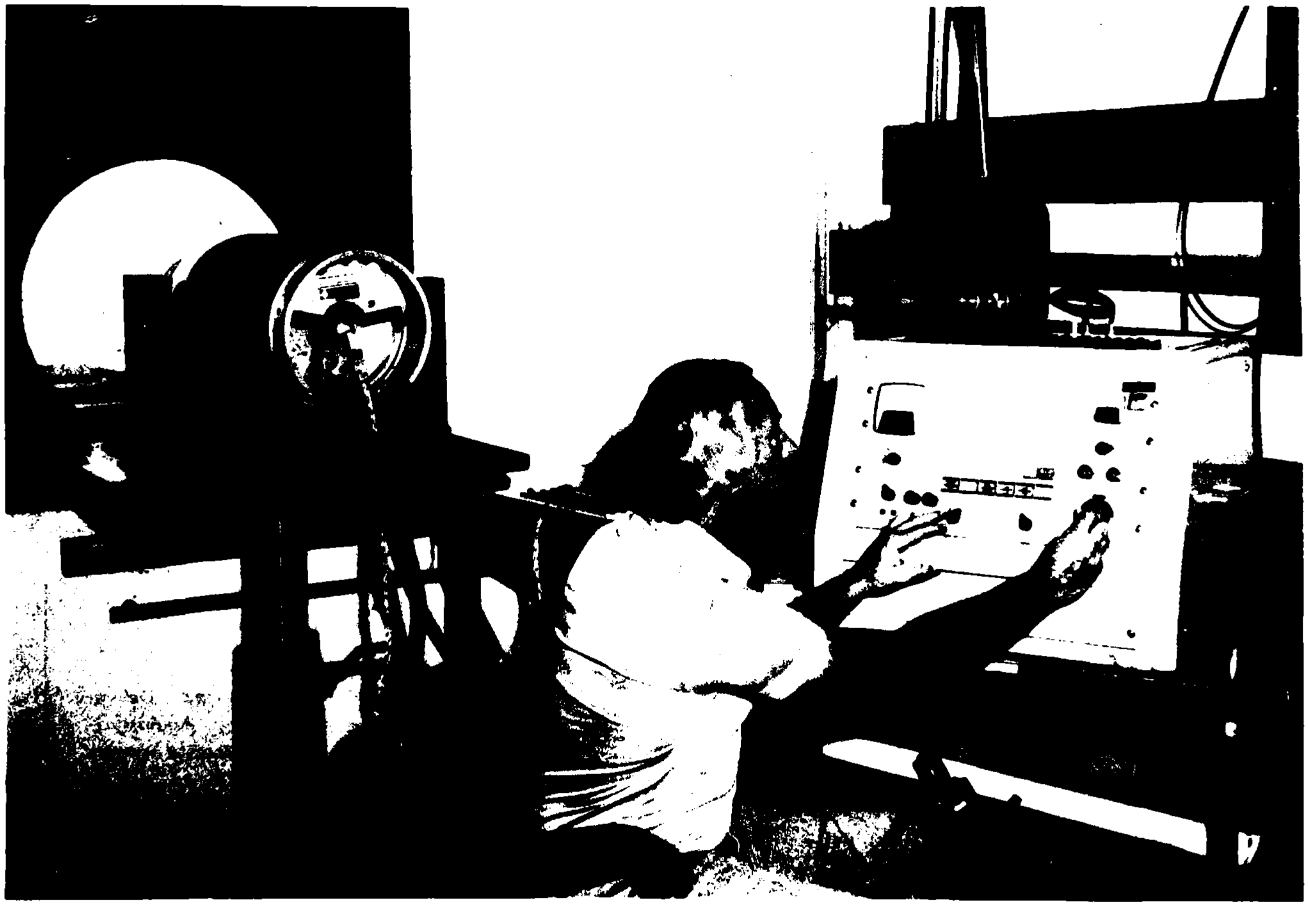
Development of Improved Missile Launch Algorithms

IR MAVERICK STATIC FIELD EVALUATION

The IR Maverick static field evaluation was conducted by the Avionics Laboratory in support of the Maverick SPO of the Aeronautical Systems Division. The evaluation was designed to provide performance data to the SPO for use in the IR Maverick production Defense Systems Acquisition Review Cycle (DSARC). The evaluation approach was two-fold. First a series of in-house laboratory tests were made to characterize the baseline performance. Tests such as modulation transfer, minimum resolvable temperature, field of view, video spectral response, etc. were made. Secondly, in-house static field tests were done on the Maverick. The Maverick was mounted in a tower and looked out through a real world path at a controlled thermal target. During the field tests, simultaneous measurements were made of local weather conditions, IR atmospheric transmission, target-background thermal contrast, and video signal-to-noise ratio or Maverick image quality.

These tests, the first government laboratory tests performed on an IR Maverick, provided a valuable data base for comparison against contractor supplied data. Because the field tests were static, the Maverick was operated in weather regimes such as snow, rain, and fog, which would have grounded a flight test program. Substantial Air Force money was saved by avoiding a contracted evaluation. The Avionics laboratory is the only DOD organization that accurately and simultaneously measures weather conditions, thermal contrast, path transmission, and electro-optical sensor performance. The field test data represents the only accurate and complete data base that can be used to quantitatively assess atmospheric effects on electro-optical sensor performance.

Lt. Michael F. Devine, AFWAL/AARI, 513-255-6361



IR Maverick Static Field Test

FORWARD LOOKING ACTIVE CLASSIFICATION TECHNOLOGY

Forward Looking Active Classification Technology (FLACT) was a program to determine the feasibility of performing forward looking automatic target classification. Under this program, the Air Force has been successful in developing a new set of neighborhood processing algorithms which perform automatic classification of tanks and trucks using a CO_2 laser radiation source and detector. The data used to develop and test these algorithms were collected in a forward looking, low depression angle geometry from both static and moving platforms. The target and background characteristics of this geometry, which were combined with speckle and glint noise due to the frequency fluctuations of the return imagery, made this a unique problem not previously researched. Previous Avionics Laboratory efforts had developed a special purpose breadboard computer which solved the neighborhood processing algorithms for the down-looking, direct detection, laser sensor data. These efforts had been very successful in automatically classifying targets of interest. The transition to the forward looking frequency fluctuation sensor data required radical, new approaches in algorithm architecture. The FLACT program developed very effective speckle noise reduction, scene segmentation, and target classification algorithms. Test results indicated that automatic classification was possible with very low false alarm rates. The FLACT program produced valuable data on: optical and electronic design problems for relative-range heterodyne CO_2 laser sensors; target and decoy reflectivity statistics for laser sensors; identification of target features usable in automatic target classification algorithms, and major design issues for algorithms performing target classification which minimize false alarms from background clutter. Applications are many and varied and apply to any mission where the requirement exists for separating targets of interest in real-time from conflicting targets and backgrounds.

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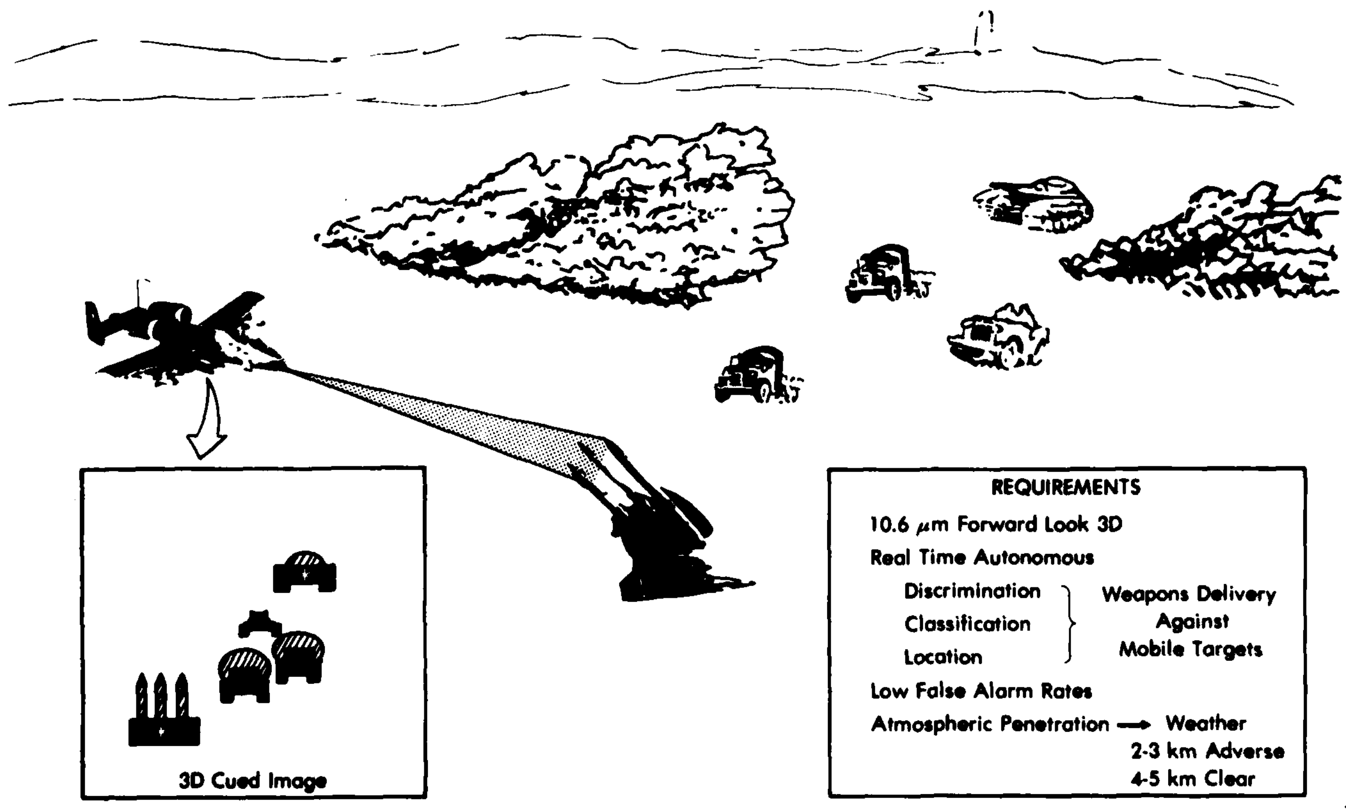


Concept

Facilities

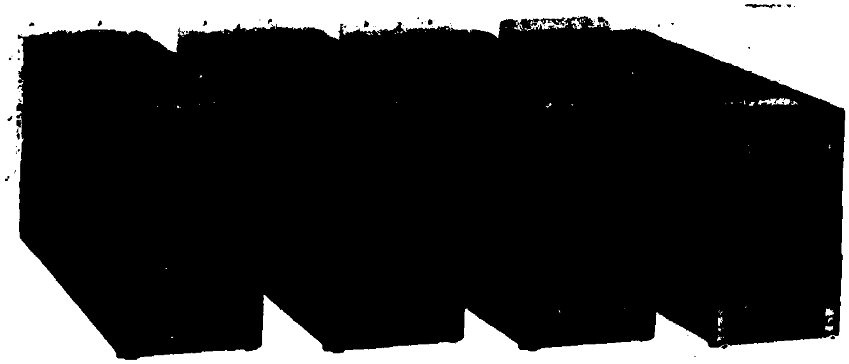
Data Processing Results

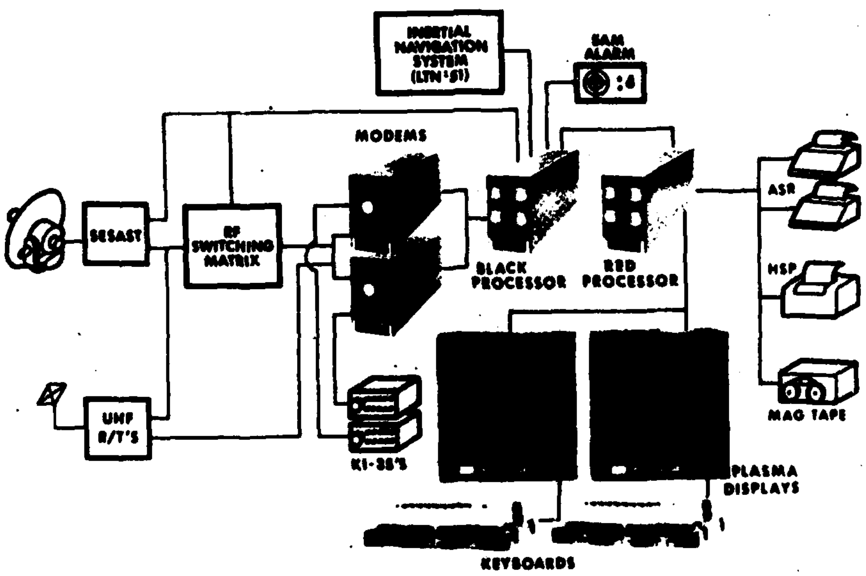
COMMAND POST MODEM/PROCESSOR

The newly developed command post modem/processor (CPM/P) provides the primary operator interface to the ASC-30, small EHF/SHF airborne SATCOM system. The system is currently being flown and demonstrated aboard a KC-135 test bed aircraft. This modem/processor provides three different modulation/demodulation formats, aligns two UHF and one SHF terminal according to pre-stored data sets, and passively points a narrow beam SHF antenna toward the satellite in a dynamic airborne environment. The CPM/P is capable of commanding selected satellites while airborne. This capability is achieved in a flight qualified arrangement of four black boxes weighing 180 pounds total and less than two cubic feet in size.

The CPM/P equipment, when operated with the EHF/SHF airborne SATCOM system, is designed to provide the SAC E-4 or EC-135 Airborne Command Post with reliable, jam resistant command and control communication capability by means of the AFSATCDM and DSCS Satellite Systems. Using the CPM/P equipment provides the AFSATCOM System with increased antijam capability and reduced operator requirements. The CPM/P reduces the operator personnel requirements from three to one. Automatic monitoring of active satellite networks, use of formatted, prestructured messages, and automatic sequencing of emergency action messages, through a number of satellites, are a few of the features that reduce operator workload. Stored satellite ephemeris information allows operator selection of any one of 40 satellites for system operation. Satellite range, range rate, and antenna pointing are automatically calculated when the operator selects a satellite network.

James J. Foshee, AFWAL/AAAI, 513-255-2697





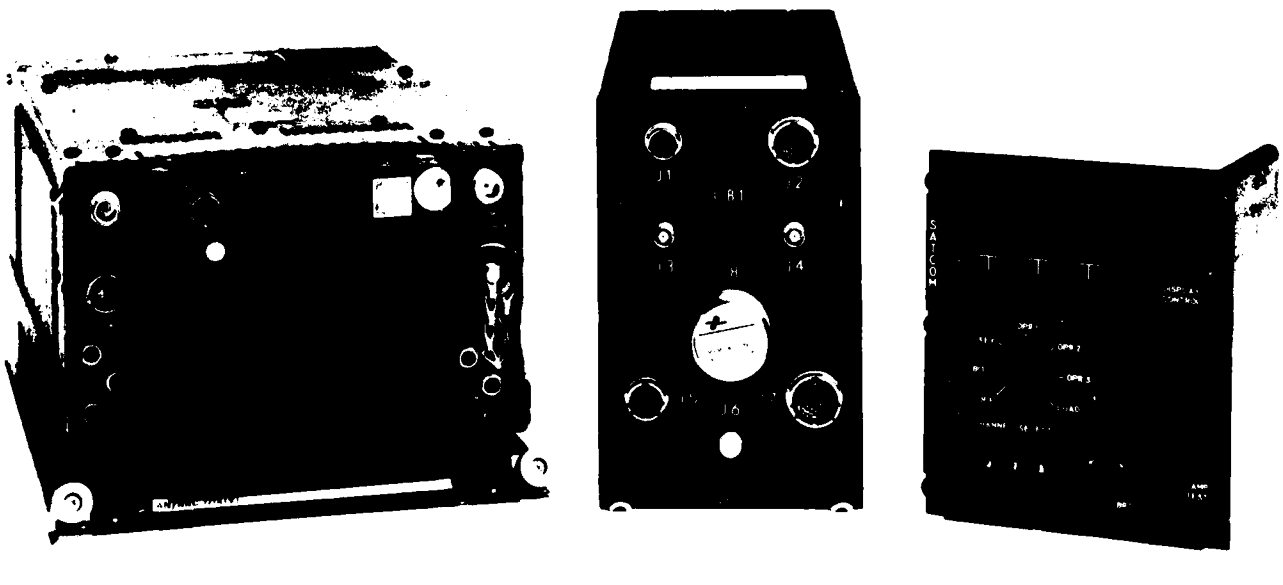
CMP/P Primary LRU's

TECHNIQUE FOR SIMULTANEOUSLY MONITORING MULTIPLE SATELLITE CHANNELS

The Avionics Laboratory has developed a UHF Satellite Communications (SATCOM) modulator/demodulator (modem). This modem monitors a priority channel on one satellite and periodically samples another channel on a backup UHF satellite to determine if an emergency action message (EAM) is being disseminated from the backup satellite. The sampling of the second satellite is done with only a minor degradation in performance of the primary channel. A high probability exists of copying the EAM if it is sent on the backup satellite. The new capability will only require the reprogramming of two memory boards in the operational AFSATCOM duel modem currently installed on SAC B-52 aircraft. No other hardware modifications are required.

The AFSATCOM System is a currently operational satellite communication system installed on B-52, FB-111, and EC-135 aircraft. The operational AFSATCOM hardware is not able to recognize interference on the primary channel and does not switch to a more robust link. The Avionics Laboratory has developed and flight tested a modification to the AFSATCOM hardware which will periodically sample the more robust channel and switch to the channel when it is activated. This capability greatly increases the reliability and operational utility of SAC's AFSATCOM UHF system. Because the current operational hardware can be modified by the field replacement of two memory boards, significant reduction in cost and time to implement this new capability into the operational fleet will result. The minor degradation in performance on the primary channel and the low probability of a false channel switch means that implementation of the new capability will not degrade current system performance but will enhance the reliability of EAM dissemination.

James J. Foshee, AFWAL/AAAI, 513-255-2697



Dual Modem Terminal

STANDARD SOFTWARE SUPPORT

The Air Force has been striving for flight vehicle standardization of both hardware and software used in embedded computer systems (ECS). Recent Air Force direction specified that the Jovial J-73 high order language (HOL) and MIL-STD 1750A computer instruction set architecture (ISA) will be used for ECS software development. The Avionics Laboratory developed a Jovial J-73 complier and a system of MIL-STD 1750A support software (assemblers, linkers, and simulators). This software, the only available capability compatible with both MIL-STD 1589B, Jovial J-73 HOL, and the MIL-STD 1750A computer ISA, has been transitioned to requesting government agencies and industry organizations. Sixty-three copies of the complier and 30 copies of the support software have been distributed.

To produce interim J-73 complier, an existing mature (nearly error free) J-73/1 compiler was modified. This approach developed the J-73 language by merging two other Jovial languages, J-73I and J-3B. Previous effort had developed a J-73/I complier that could be modified for the J-73 language. This effort resulted in a J-73 compiler produced in a shorter time and at approximately one-fifth the cost of a completely new compiler development. An added benefit of this procedure was that the J-73 compiler is itself more error free. The development of the 1750A support software has followed a similar upgrading process and yielded similar results.

Significantly, the Air Force now has the needed capability to begin compliance with the standardization efforts required by MIL-STD's 1589B and 1750A. Several programs have been committed to use these standards, notable the Lantrin and KC-135 modernization programs in ASD and the Data System Modernization (DSM) program at the AF satellite control facility.

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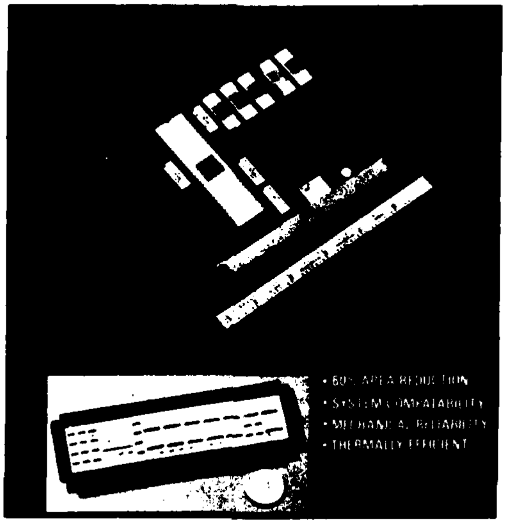
HIGH DENSITY PACKAGING USING HERMETIC CHIP CARRIERS

Early hermetic chip carriers were developed in various nonstandard configurations. As the result of an Avionics Laboratory in-house test and evaluation program, it was learned that the corner pads on these early devices failed considerably sooner than the side pads during temperature cycling. Following the identification of this deficiency, a family of three layer packages using 40 and 50 mil pad centers and no corner pads were developed under contract. This family of hermetic chip carriers has since been recognized as the standard by the Joint Electron Device Engineering Council.

Another Avionics Laboratory contract effort sponsored accelerated life tests on both test and functional circuits to evaluate the reliability of the interconnection between these new hermetic chip carriers and various substrate materials used for second level interconnection in military electronic systems. The accelerated life testing provided significant input into the reliability data base for hermetic chip carriers; helped identify deficiencies requiring further R&D; and indicated that the smaller hermetic chip carriers perform well at stress levels descriptive of typical military systems. It was determined that chip carriers with many pads need a substrate with a thermal expansion coefficient that matches the ceramic chip carrier thermal expansion coefficient. Various substrate materials are being checked by industry in recognition of the need identified during the AFWAL sponsored tests. The development of a completely satisfactory substrate for large hermetic chip carriers remains to be done. Hermetic chip carriers offer significant advantages over state of the art dual in-line packaging of integrated circuits. The advantages are: up to 60 percent reduction in weight and volume; improved thermal characteristics having a positive impact on realiability; and improved electrical performance due to lower resistance and inductance of short leads. The 50 mil center family of hermetic chip carriers are now included in MIL-M-38510 and are being used in newly developed military avionics equipment.

Alan J. Tewksbury, AFWAL/AADE, 513-255-6553.



Microprocessor Module Miniaturization with Chip Carriers

SOBEL EDGE EXTRACTION CIRCUIT

The Avionics Laboratory has designed and demonstrated a SOBEL edge extraction circuit for use in target detection and classification. The SOBEL is a 3 x 3 pixel sliding window-type algorithm used to highlight (enhance or extract) edges within video pictures prior to processing by the target detection algorithms in an EO system. In-house investigations have shown that the SOBEL algorithm and a close approximation, which can be implemented by the same hardware (the PREWITT algorithm) are excellent edge enhancers. The SOBEL circuit design was done in-house at the functional block-diagram level and then carried down to the gate level. The design, which requires some innovative techniques to reduce circuitry and increase throughput, has been breadboarded (3 boards) and verified. Local analysis in the processor laboratory and outside feedback has shown that a large number of applications for this circuit exist. The circuit can be implemented on a single chip using well understood, IE current production techniques, integrated circuit technology, and design rules.

A primary approach to target identification is to analyze the various patterns in the video frame to determine the type of target being viewed. This type of processing requires that fast and accurate edge enhancement preprocessing be performed. Hardware to perform a square root-of-the-sum-of-the-squares magnitude computation in real time complicates the SOBEL or PREWITT algorithms. Circuits to do these computations have been implemented but an approximation routine is used in the sum of each term. This procedure is undesirable because errors are introduced during this critical preprocessing operation. An error can influence the success of subsequent processing functions which are dependent on the quality of the edges found. A table-look-up scheme was developed to perform the squares and square roots. These tables were too large for present integrated circuit capability, so methods were developed to reduce the size of the tables and not seriously degrade the accuracy. The result of these efforts is a circuit which can perform at the required speed and can be implemented with today's production integrated circuit technology. SOBEL circuits will cost less and require fewer devices to perform the edge preprocessing than E-O signal processing circuits being developed under the VHSIC phase I program. VHSIC devices are programmable and therefore, better suited to perform the processing following the edge enhancement.

Robert M. Conklin, AFWAL/AADE, 513-255-4448

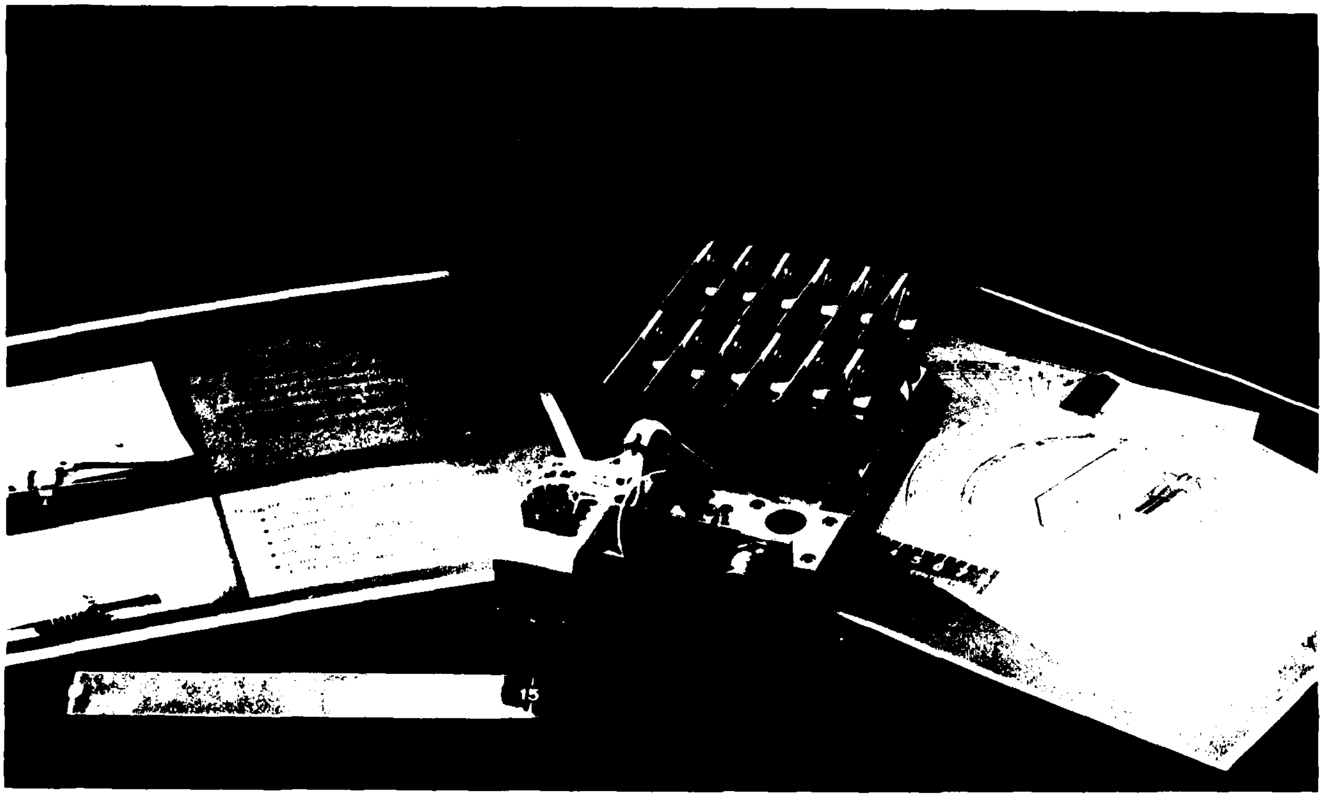
Original Image

Sobel Of Image

DEVELOPMENT OF GALLIUM ARSENIDE IMPATT DIODES AND POWER COMBINERS

Gallium Arsenide (GaAs) semiconductor materials research performed for the Avionics Laboratory has provided a significant state of the art increase in available solid state RF source power and efficiency at 10, 20, and 44 gigahertz (GHz). Gallium arsenide impact avalanche transit time (IMPATT) diodes have demonstrated: 45 watts pulsed power, 13 watts average power, and 22 percent efficiency at 10 GHz; 5 watts average power, 20 percent efficiency at 20 GHz; and 2 watts average power and 18 percent efficiency at 44GHz. These results represent almost a 100 percent improvement in device efficiency over their silicon predecessors. These achievements were the result of in-depth theoretical and experimental research efforts which encompassed advances in GaAs crystal growth and processing techniques, packaging technology, diode circuitry, and improved measurement and analysis methods of the physical properties of the IMPATT diodes. Specific areas of technology advancement include: improved wafer reproducibility through the use of microprocessor control of the vapor phase crystal growth reactors, automation of the GaAs wafer characterization measurements from which device performance expectations can now be formulated, adoption of the multi-mesa geometry for improved diode thermal resistance, and the evolution of new theoretical diode models which further the understanding of the physics of operation. Significant advancement has also been made in multidiode power combiners, resulting in output power comparable to the best traveling wave tube amplifiers. The advantages of high reliability, small size, and efficiency enables the solid state amplifiers to be an extremely attractive candidate for space communications, active missile seekers, and terminal guidance sensors.

Robert M. Blumgold, AFWAL/AADM, 513-255-2062



Diode Power Combiner

SECTION III
FLIGHT DYNAMICS LABORATORY

ADVANCED BALLISTIC REENTRY VEHICLE COMPOSITE SUBSTRUCTURE

As part of the MX missile development program, the Flight Dynamics Laboratory conducted a program to evaluate the unique properties of advanced composites as the load carrying substructure of an Advanced Ballistic Reentry Vehicle (ABRV). The Laboratory's program involved the design, fabrication, and structural test of a full-scale composite substructure built to ABRV specifications.

A detail design of the full ABRV substructure was developed, fabricated, and successfully completed nuclear impulse simulation testing with no visible structural damage. A moisture barrier concept for the payload section, consisting of electro-deposited copper on the inner surface of the composite substructure and aluminum foil cocured to the substructure's outer surface, was developed and verified through test. The ABRV development unit was successfully tested to 124 percent design ultimate load, demonstrating the capability of the full-scale substructure to withstand expected flight loads.

The success of the Laboratory's advanced composites program was a key factor in prompting the MX program office to select the ABRV as the reentry vehicle for the MX missile. The ABRV has been baselined as an aluminum/composite hybrid structure, with the aft third of the structure being graphite/epoxy. Compared to its metallic counterpart, the composite aft end saved 3.5 lbs., enabled ABRV to meet critical MX weight requirements, and improved ABRV's yield and accuracy. At the same time, the superior fatigue characteristics of the graphite/epoxy aft end improved ABRV's ability to withstand the severe horizontal transport environment. The cost to upgrade existing Mark 12A RVs to ABRV's level of safety and structural integrity, if possible, would be high. The modifications to Mark 12A would probably degrade its performance and require a recertification.

The incorporation of a composite aft end on ABRV and the work completed under the Laboratory's advanced composites program paves the way for an all composite substructure on the next generation of reentry vehicles. Such a substructure offers the potential for even lower cost, lower weight, and improved system performance.

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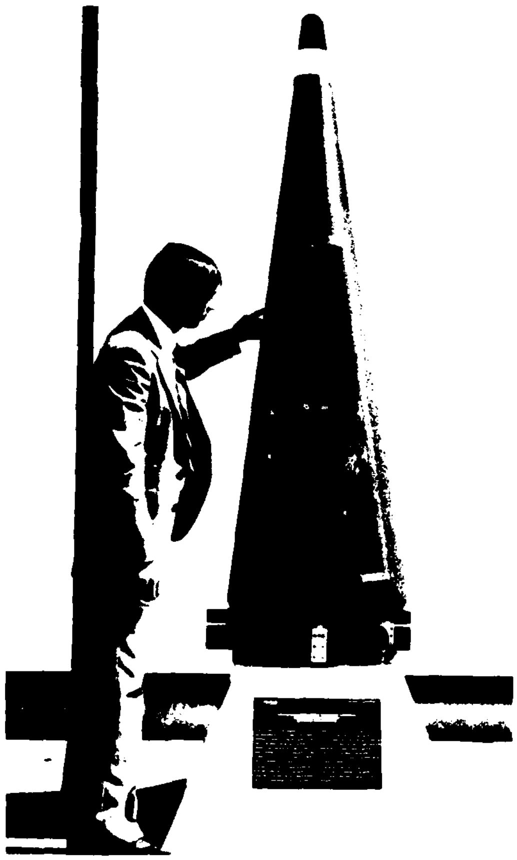

ABRV Showing Composite Substructure

STRUCTURAL TEST OF BUILT-UP LOW-COST ADVANCED TITANIUM STRUCTURE

New aircraft weapon systems will likely continue to be procured in an environment of increasing vehicle performance requirements coupled with an ever growing concern for weapon system costs. The airframe structure represents two-thirds of an aircraft's empty weight and one-half the cost. The new technology of superplastic forming with concurrent diffusion bonding (SPF/DB) of titanium is very promising for achieving significant reductions in structural weight and cost. This technology is being demonstrated and verified by the AFWAL Flight Dynamics Laboratory's structural integrity test program of a built-up low-cost advanced titanium structure (BLATS).

The demonstration test article, a full-scale advanced tactical fighter wing box structure, successfully completed two equivalent lifetimes of fatigue cycling (a lifetime is defined as flight-by-flight cycling for 2935 flights). Six locations were then picked to place saw cuts as crack intiation sites, and damage tolerance testing began. Careful monitoring of the structure continued through the third lifetime of cyclic load application, and no cracks were detected. Four of the six crack initiation sites were enlarged during the end of third life inspection and testing was resumed. A crack in the aft right hand wing lower spar cap was discovered at approximately 20 percent of cycling into the fourth lifetime.

Various repair techniques were evaluated, and a plate to bridge the crack was designed, fabricated, and installed. Laboratory personnel successfully removed half of the cracked surface for evaluation. This success was a major step in allowing analysis of the crack propagation since, before, it was generally thought the crack face could not be inspected without major damage to the structure. BLATS durability characteristics are continuing to be established through resumption of spectrum load testing with concurrent damage tolerance testing.

The success of this superplastic formed with co-diffusion bonded and welded primary structure is a major step in advancing the state of the art in titanium technology, while reducing production weight and cost.

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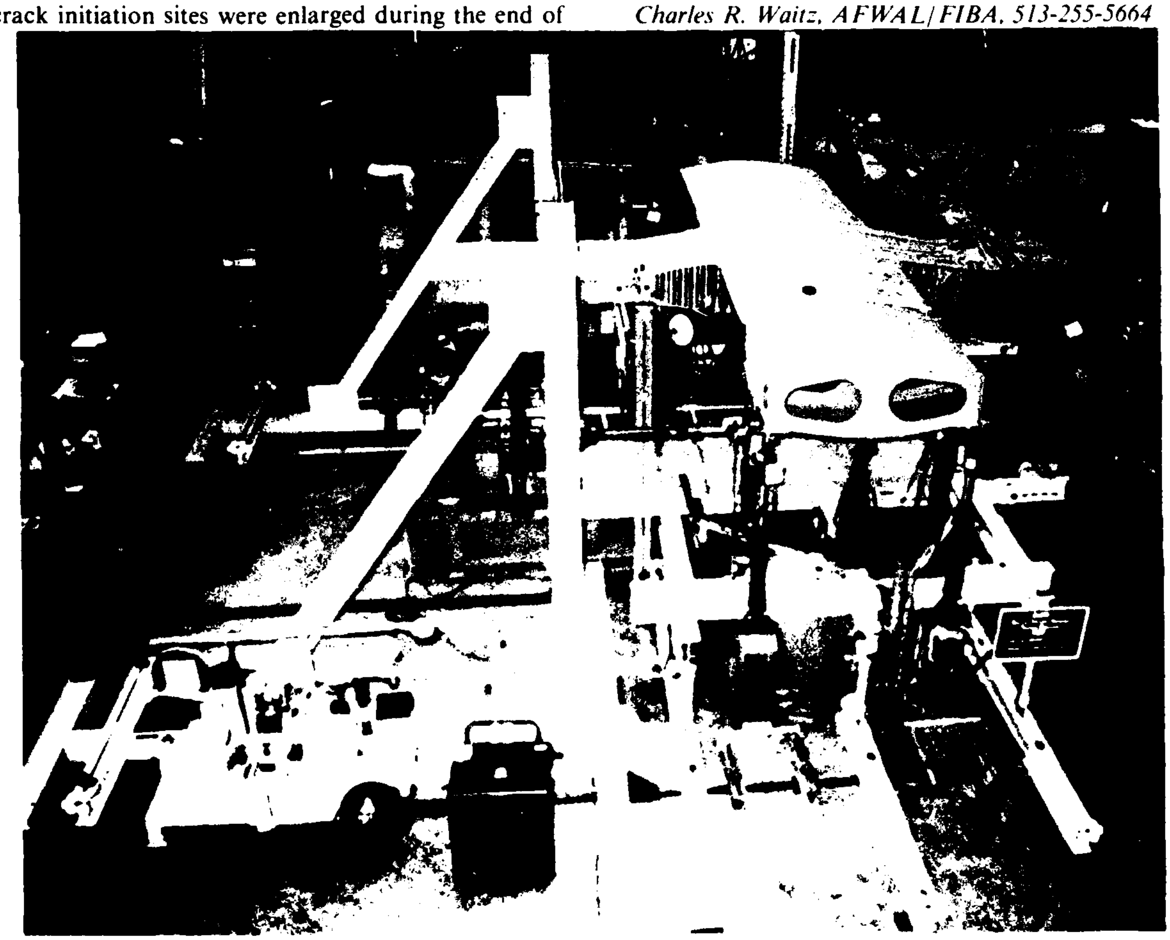

BLATS Test Set-Up

WIND TUNNEL INVESTIGATION OF DIGITAL ADAPTIVE FLUTTER SUPPRESSION

In order to perform a variety of missions, fighter aircraft must carry many different combinations of external stores. Mounting of stores on the wings can cause significant reductions in wing flutter speeds and result in different flutter modes with a wide range of frequencies. Passive techniques for preventing flutter often result in reduced aircraft performance and degraded survivability. Under a Flight Dynamics Laboratory program, adaptive flutter supression was achieved for the first time.

The Laboratory's program involved the design and test of digital adaptive concepts which were previously identified as promising for actively suppressing wing/store flutter. The first phase of the program involved the digitization of the existing analog control laws for flutter suppression, real time simulation, and wind tunnel tests of the digital control laws. In the second phase, an adaptive control concept was successfully demonstrated for wing/store flutter suppression. For the wind tunnel demonstration, the aeroelastic model shown in the figure was tested with external stores on an outboard pylon and on the wingtip at a speed which did not cause flutter. The tip missile was suddenly ejected, resulting in a configuration which was violently unstable. In less than 0.2 second, the adaptive control system sensed that the model was unstable, performed the necessary parameter identification, gain/phase compensation, and actuated the trailing edge control surface to produce aerodynamic forces on the wing which damped out the potentially destructive flutter motion.

Active flutter suppression is a promising alternative for controlling wing/store flutter without decreasing aircraft performance. The eventual integration of the active flutter suppression system into advanced fly-by-wire aircraft control systems holds the promise of extending aircraft performance with a minimum increase in control system hardware. To accommodate the variety of possible flutter modes involved, an adaptive flutter suppression system that automatically adjusts for changes in flight condition and store configuration is highly desirable. When fully developed and demonstrated, active flutter suppression will enhance the flight safety and store-carrying versatility of tactical fighter aircraft.

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FDL Model Prior to Store Ejection

FUEL TANK SEALANT METHODS, DURABILITY, AND TEST

Leaks from aircraft integral fuel tanks are a high cost item for Air Force using commands. These costs are incurred directly by the maintenance required to repair leaks and, indirectly, by the reduction in aircraft availability. Under a Flight Dynamics Laboratory program, a fuel tank test facility was designed and fabricated, and fuel tank fastener/sealant systems were evaluated for leak susceptibility.

During the 37-month effort, 11 structural test components representative of fighter wing integral fuel tanks were designed, manufactured, and tested in the facility to develop effective methods for evaluating and certifying the fuel containment integrity of future integral fuel tanks. The 11 test articles, each with a different sealing concept and fastener system, contained deliberate typical manufacturing defects to determine how tolerant the different sealing concepts were to these discrepancies. The testing consisted of applying F-16 truncated cyclic structural loading with superimposed fuel tank pressure and environmental conditions, both with and without JP-4 fuel. A total of 2,273 real hours of environmental exposure and 208,000 equivalent flight hours of combined structural/environmental testing were accomplished. Leakage and repair data were accumulated and provided the data base for comparing the different sealing concepts as to their leak integrity and sensitivity to design and manufacturing defects.

The fuel tank technology program also successfully developed a new analytical method for predicting fatigue of aircraft fuel tank skins precipitated by fluid-structure interaction dynamics. Prior investigations of fuel tank fatigue using only a strength type spectrum fatigue approach did not adequately account for fluid slosh effects. The utilization of this new analytical method has the potential of significant cost savings in the areas of improved durability and reduction of aircraft down time due to fuel leaks.

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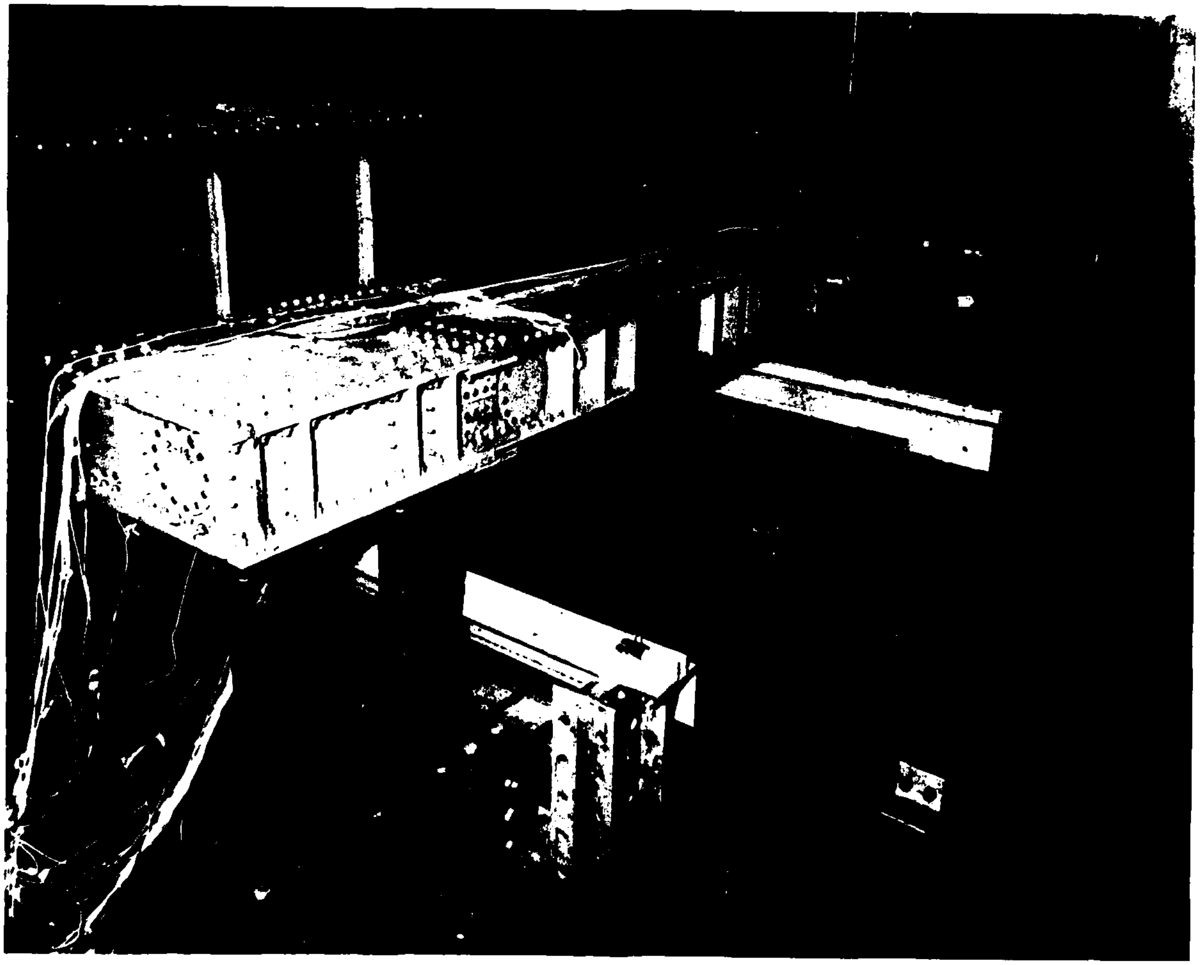

Fuel Tank Test Facility

COMPOSITE REPAIR OF ALUMINUM ALLOY AIRCRAFT COMPONENTS

One of the problems with aluminum as a structural material in aircraft is fatigue cracking, which occurs when the structure undergoes many cycles of loading. This phenomenon usually leads to cracking, often in areas of concentrated stress such as bolt holes. A Flight Dynamics Laboratory program has demonstrated significant reductions in stress intensity and crack growth characteristics of aluminum alloy specimens using advanced composite patches.

A standard repair of cracked aluminum utilizes an aluminum patch bolted to the structure. The Laboratory program investigated the effect of utilizing an adhesively bonded repair patch made of an advanced composite material (boron/epoxy) instead of aluminum. This repair method offers several advantages over a bolted, metal patch. First, there are no severe stress concentrations created with the bonded method since bolt holes are not drilled in the cracked structure as they are when using the metal patch. Secondly, the boron/epoxy patch itself is a stiffer, more fatigue resistant patch than its aluminum counterpart. For an aircraft with exterior repair patches, the thinner composite patch can be more valuable in helping to maintain satisfactory vehicle aerodynamics. The composite patch is also easier to mold to curved or irregular surfaces, and the adhesive bond creates a sealed interface which helps to prevent corrosion.

In the Laboratory's test program, edge cracked aluminum coupons, precracked to a 0.3 inch crack length, were used. Boron/epoxy patches were cocured to the aluminum using AF 163 adhesive and a 250° F, vacuum-pressure cure cycle. The structure was then cycled to failure, using both constant amplitude and spectrum loading. Initial results for 1/16 inch cracked aluminum have shown patched specimens to have an order of magnitude greater lifetime extension. For 1/8 inch specimens, lifetime extensions were at least seven times greater for patched specimens than for unpatched.

Conventional procedures for repairing cracked aluminum are often time consuming and structurally inefficient. The improved repair method using composite patches will increase aircraft availability and reduce maintenance costs.

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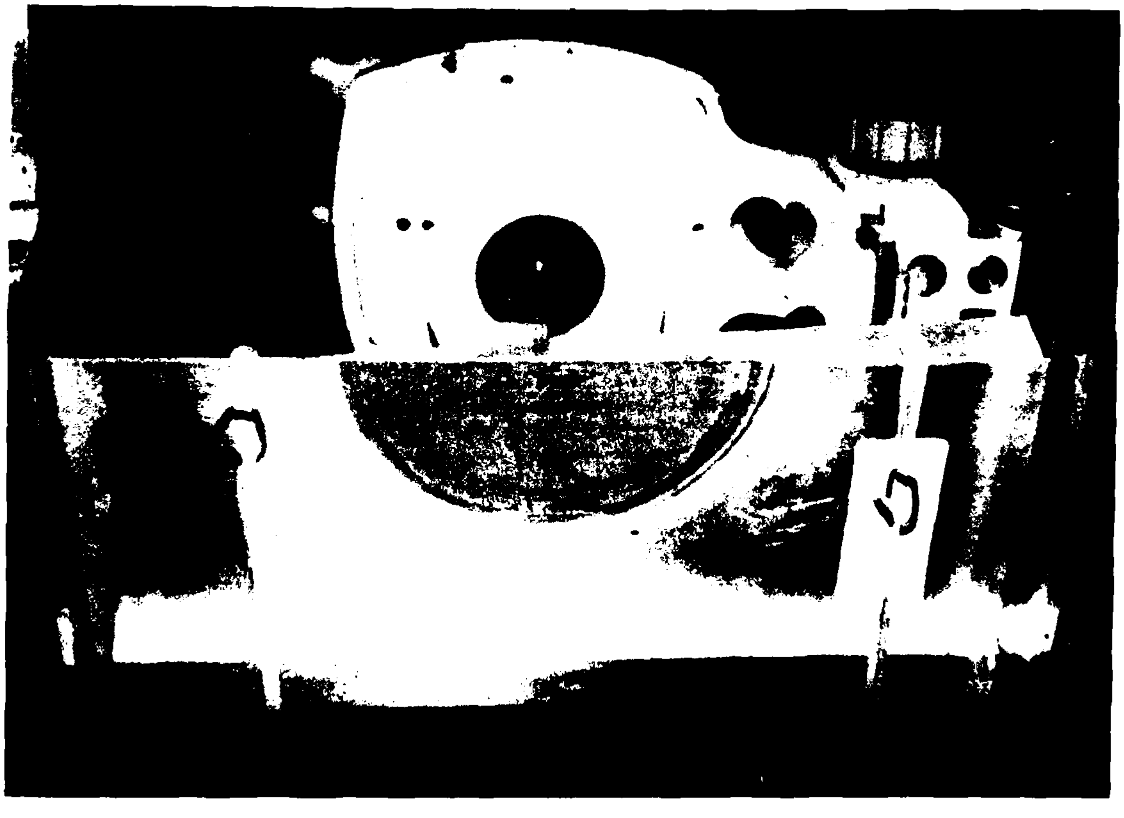

Patched Side of Aluminum Specimen and Microscope for Crack Measurement

DUAL MODE ADAPTIVE LANDING GEAR

Under a Flight Dynamics Laboratory program, a dual mode adaptive landing gear concept was recently demonstrated on an L-1011 aircraft. The successful evaluation of the gear demonstrated significant reductions in dynamic ground loads and accelerations during rough runway operations.

All three landing gears on an L-1011 aircraft were modified by adding a nitrogen strut chamber and pressure system. This system provides an optimized strut for the landing mode (initial impact only) and a switch-over control that provides an increased nitrogen volume at a higher pressure for landing rollout and taxiing. In the latter modes, a softer spring rate is achieved, including additional strut stroke for operation on rough runways.

An asphalt bump 86 feet long x 3 inches high, representing a repair mat profile, was installed across the taxiway. Taxi runs at approximately 40, 60, and 80 knots were conducted over the test bump with all three gears in the normal L-1011 service and dual mode adaptive configurations. Results showed that, in the modified configuration, peak vertical center of gravity acceleration during dynamic loading was reduced as much as 53 percent and landing gear peak dynamic loads were reduced as much as 62 percent.

The concept validation represents the first time that a dual mode adaptive gear has been demonstrated on a transport aircraft. This key advancement in the state of the art provides increased sortie generation in a battle environment and allows aircraft operation on damaged/repaired runways and alternate low strength rough surfaced operating strips. The system can be easily retrofit on existing aircraft, uses off-the-shelf hardware, and has negligible cost, weight, and volume penalties for large transports.

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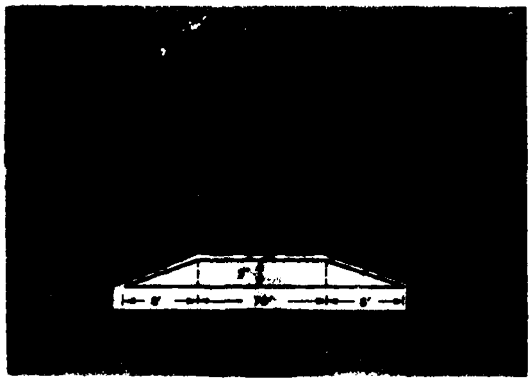
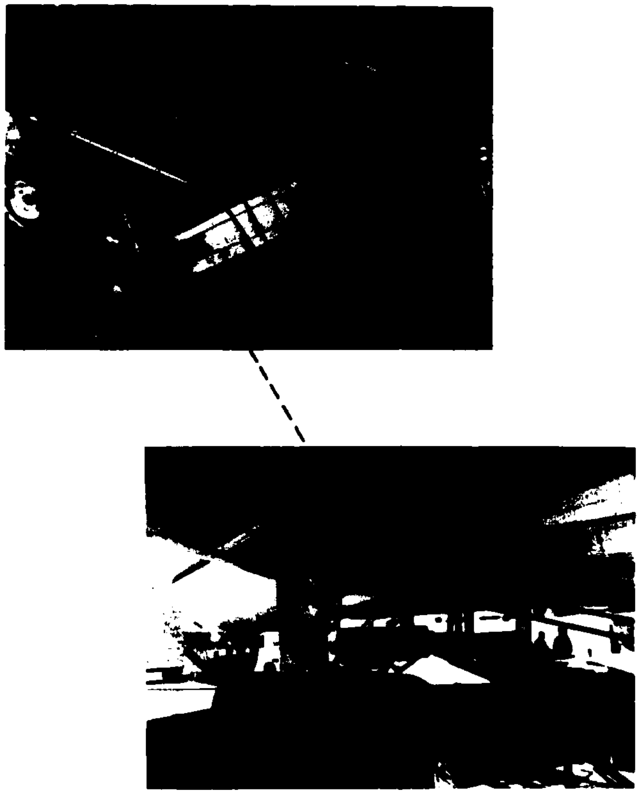


Asphalt Bumps



Nitrogen Strut Chamber Installation on L-1011 Landing Gear

BALLISTIC EVALUATION OF HALON FIRE SUPPRESSANT

Military aircraft are often required to operate in hostile environments in which they are subjected to enemy attack. An aircraft that sustains a hit in such an environment has a high probability of being lost due to an explosion or fire. The Flight Dynamics Laboratory recently completed a program that investigated fuel tank inerting as a means for suppressing fire and explosion in and around aircraft fuel tanks.

At the request of the Aeronautical Systems Division (ASD), the Laboratory conducted an experimental test program to evaluate the possible change in effectiveness of Halon 1301 gas as a fire suppressant agent in the ullage of a fuel tank when subjected to various ballistic threats.

The test program was conducted using a tank wall simulator (TWS) and propane gas to simulate the fuel tank ullage vapor. Combinations of fuel tank initial pressures (16-20 psia), temperatures (70°-110°), and percent of Halon 1301 (6%-15%) present in the TWS were subjected to two ballistic threats. During the course of the evaluation, 36 tests were conducted using 0.50 cal armor piercing incendiary (API) and 10 tests using foreign 23 mm high explosive incendiary (HEI). The test results demonstrated that the 12 percent Halon by volume used in the fuel tank was sufficient to inert the tank against the 0.50 cal API. The 12 percent Halon 1301 is also sufficient to protect the fuel tank against the 23 mm HEI if sufficient venting area exists. However, when venting area is not present, the required inertant would have to be increased substantially. The inerting ability of Halon 1301 was not appreciably affected by an increase in fuel tank pressure or temperature.

By virtue of this research effort, significant advancements have been made in understanding the effectiveness of Halon 1301 in inerting aircraft fuel tanks. This will help to prevent fire and explosion in the fuel tank ullage of combat aircraft, thereby greatly reducing aircraft vulnerability.

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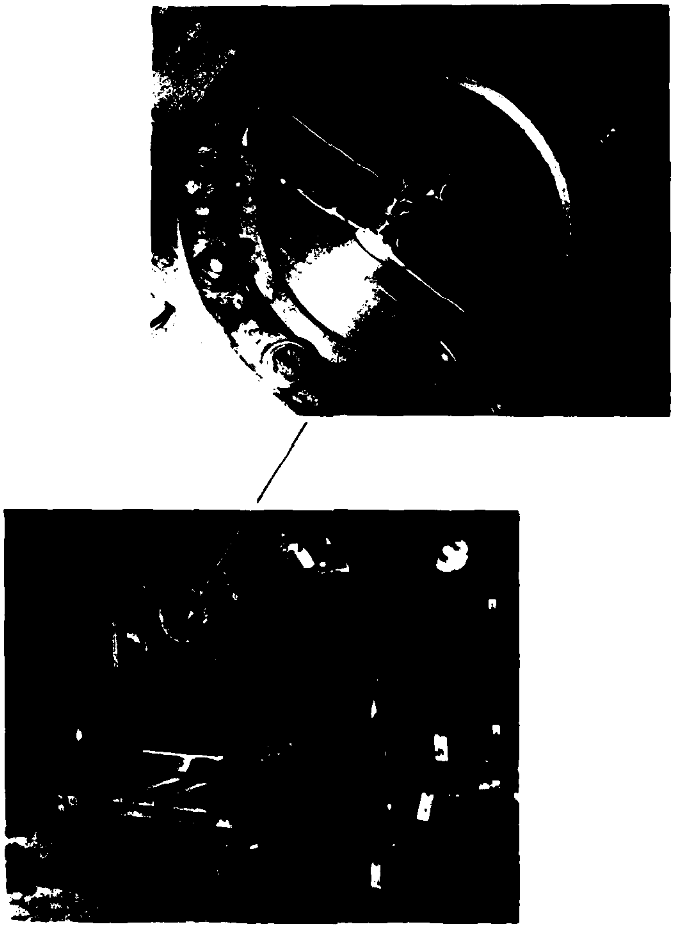

Fuel Tank Simulator Test Set-Up

AIR FORCE STANDARD CRYOGENIC COOLER TECHNOLOGY TRANSITION

Past development programs aimed at the application of various cryogenic coolers to infrared sensors have clearly identified the need to increase reliability and reduce cost by standardizing cooler designs. To meet this need, a flight qualified standard cryogenic cooler, developed by the Flight Dynamics Laboratory, is presently being established as an Air Force inventory item.

The Air Force standard cryogenic cooler was designed to operate at 77° K to cool infrared detectors for airborne application. The cooler weighs 11 pounds, operates on the heat driven compressor Vuilleumier (VM) cycle using 350 watts of input power, and provides one watt of cooling with a design operating life of 2200 hours. It was developed to satisfy the majority of 77° K cooling requirements for aircraft and tactical missile infrared detector systems.

The standard cooler has been integrated into and flight tested with the AAR-34, a tail warning infrared system on the F-111 aircraft. This represents an important milestone since the present cooler system has had a low operational life (200 hours mean-time-between-failure) because of the high vibration levels (16.5 g root mean square) that can occur in the F-111 tail area. The standard cooler has been successfully tested for an average of 1500 hours under various vibration levels, including 16.5 grms random vibration. The Air Force Logistics Command (AFLC) is in the process of establishing the standard cooler as an inventory item for the F-111/AAR-34 system.

The potential for life cycle cost savings offered by the standard cryogenic cooler is significant. Service use is expected to be several times longer than the current cooler system, thus reducing maintenance and servicing actions, requiring fewer spares, and resulting in a much lower operational cost ownership. The Air Force standard cryogenic cooler's operational flight testing meets F-111 operational and logistic needs in an economical manner and is an excellent example of an important technology transition.

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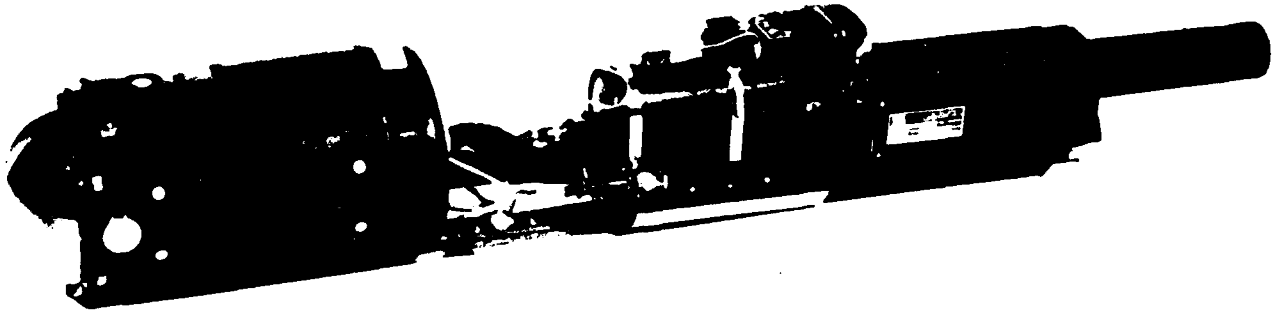

Air Force Standard Cryogenic Cooler Integrated into AAR-34 Tail Warning System

C-130 LIGHTNING SIMULATION VALIDATION

Recent advances in aircraft technology have tended to raise the susceptibility of critical avionics subsystems to damage or upset by lightning. These advances make it increasingly important that lightning qualification and test techniques simulate all the electromagnetic coupling mechanisms and parameters present in the lightning environment. The Flight Dynamics Laboratory recently conducted a program where laboratory simulated lightning induced effects were experimentally obtained and favorably compared to natural lightning induced effects.

The test aircraft was a WC-130 "Hurricane Hunter" that was instrumented to acquire electromagnetic field information from active thunderstorms. The aircraft was flown for a two-month period in thunderstorms over Florida and acquired direct and nearby strike data. The aircraft was then subjected to three lightning simulation tests in an effort to reproduce the naturally occurring lightning effects. The three tests consisted of a direct current injection through the aircraft, a combined current injection and high voltage test, and a nearby radiated field test. Data were obtained from the same sensors and instrumentation used during the flight phase of the program to insure a valid comparison. An analysis was performed to compare the naturally produced lightning effects with the simulated effects to determine the most accurate test and simulation method.

This experimental test program is the first known validation of lightning simulation techniques via direct comparison with natural lightning. The information gathered will aid in developing accurate lightning simulation and test methods that can be applied to present and future aircraft to determine susceptibility to lightning induced damage or upset. These tests will then indicate the most economical and effective means of protecting sophisticated aircraft avionics against lightning, thus allowing a wider operational envelope for modern fighter aircraft.

Lt. Brian P. Kuhlman, AFWAL/FIES, 513-257-7469

WC-130 Aircraft Instrumented to Measure Laboratory Simulated Lightning Induced Effects

ROCKET-TRIGGERED LIGHTNING INVESTIGATION

New generation aircraft incorporating sensitive microelectronics and non-shielding composite airframes could possess a significantly increased susceptibility to the lightning hazard. To obtain baseline information on the characteristics and effects of lightning, and better understand the lightning-aircraft interaction, the Flight Dynamics Laboratory recently conducted a Rocket-Triggered Lightning Investigation.

The Laboratory's program proved experimentally that data for aircraft protection research could be acquired by directing triggered flashes to an instrumented target. For the investigation, a hollow aluminum lightning strike object (LSO), 8½ meters in length and ½ meter in width, was designed, constructed, and instrumented. A 20-meter tall wooden scaffold was constructed atop Mt. Baldy in New Mexico to suspend and isolate the LSO above ground plane. French wire-and-rocket lightning triggering units were deployed around and atop the scaffold to trigger lightning strikes onto and beside the LSO. During the system tests, 37 lightning strikes were triggered in 67 attempts. Data on electromagnetic fields, lightning currents, and the response of an internal wire were transmitted fiber optically from the LSO to a nearby instrumentation van. Substantive data were obtained for comparison and correlation with airborne lightning measurements.

The rocket-triggered lightning testing technique may provide a new, extremely cost-effective method of acquiring data on lightning threat characteristics. The data acquired could potentially be used to verify lightning field computer codes, and to assess the effectiveness of laboratory lightning threat simulators. In addition, a rocket-triggered lightning testing technique might find application as a means of proof-testing the hardness of full-scale aircraft and aircraft components. The first steps in exploring the vast potential of the technique were successfully accomplished through the Rocket-Triggered Lightning Investigation. Results of the program could have significant applicability to the safety of all future military and commercial aerospace vehicles which might encounter a thunderstorm environment.

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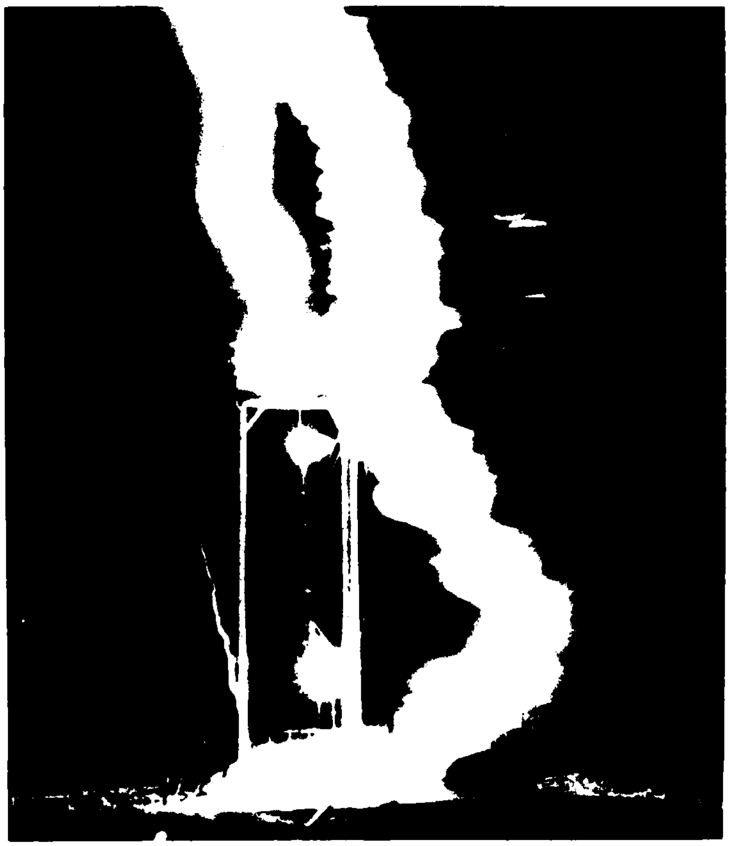

Simulated Lightning-Triggered Strike Installation

INTEGRATED FLIGHT/FIRE CONTROL

Since the advent of aerial combat, fighter aircraft pilots have had to maneuver their aircraft to a position behind the adversary and shoot from a restricted "tail chase position" to have a reasonable probability of success. This situation has been improved dramatically through a Flight Dynamics Laboratory program that developed and successfully flight tested an Integrated Flight/Fire Control (IFFC) system.

The IFFC system couples the flight and fire control systems on the attacking aircraft so that information generated by the fire control system can compute the target aircraft's position and relative motion. These data are then fed directly into the attacker aircraft's flight control system to steer out tracking errors and to present the pilot with a firing solution opportunity.

Recently, in a mock air-to-air engagement against a remotely piloted PQM-102 target aircraft, an F-15B achieved a major milestone which could alter the future of aerial combat. The IFFC equipped F-15B, using a single burst from its 20mm Vulcan Cannon, destroyed the PQM-102 in a dynamic high angle of attack, high closing speed maneuver on its first firing pass. The F-15B engaged the drone aircraft from the front quarter, 50 degrees off the nose of the PQM-102 and at closing rates in excess of 880 miles per hour. This air superiority breakthrough also demonstrated the capability to deliver bombs from maneuvering flight, 3 to 4 g at bank angles greater than 80 degrees and slant ranges to the target in excess of 3 miles, with the same accuracy as the basic wings level system. The maneuvering attack profile that was achieved provides a ten-fold increase in survivability against today's highly lethal anti-aircraft gun systems.

The IFFC program has demonstrated a dramatic technology breakthrough which will greatly improve the survivability and combat effectiveness of present and future fighter aircraft. It marks the first time that flight, fire, weapons, and pilot tasks have worked together in unconventional maneuvers never before possible using weapon systems, trackers, and flight computers developed independently of each other. The program has demonstrated that the IFFC system can provide excellent weapon delivery accuracy with reduced pilot workload for air-to-air gunnery, air-to-ground gunnery, and bombing.

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F-15 IFFC Aircraft

DIGITAC OPTICAL FLIGHT CONTROLS

Future high performance aircraft will be dependent on sophisticated flight control systems (FGSs) integrated with other avionics for mission success. To improve flight control reliability and survivability, the Flight Dynamics Laboratory has developed and flight tested a single fiber optic (FO) multiplex (MUX) data bus.

The new single FO bus replaces one of the two multifiber (210 fibers/cable) cable buses that were originally installed in the DIGITAC II A-7D test aircraft. The dual digital data bus system consists of forward and midship remote terminal (RT) units and a bus controller interface unit (BCIU) for each of the data bus channels. All flight critical data to be processed by the flight control computers and RTs are transmitted via multiplexed light signals (called a "Fly-By-Light" system) and flows through these FO MUX data buses to-from and between the dual computers and RTs. The computers serve to control the bus data traffic, flight sensor sample rates, and computation of the flight control laws. The RTs interface between the sensors, control panels, and control surface actuators; collect the flight sensor data and process the information for delivery to the computers on demand; and send command signals to the flight control actuators. Since FCSs are flight critical, this MUX system design emphasizes detection of functional failures and provides fail-operational capability.

The DIGITAC II FCS represents the first known flight demonstration of a "full up" three-axis "Fly-By-Light" control system in an aircraft. The DIGITAC A-7D test aircraft flies routinely on the "Fly-By-Light" FCS and has completed 109 flights, which include 85 flights on multifiber optic buses and 24 using the single FO bus. The "Fly-By-Light" system has performed flawlessly during these 109 flights.

The FO MUX data bus system has demonstrated a significant advancement in the method of transmitting flight critical data for computation of the control laws for the roll, pitch, and yaw axis of an aircraft. Combining FO MUX buses as part of a digital flight control system can improve flight safety, system reliability, combat survivability, and reduce weight and cost. These small FO cables can be easily distributed in the aircraft/missile as redundant cables to enhance survivability from battle damage. These FO cables are immune to lightning strikes, electromagnetic effects, and cross talk.

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A-7D Digitac II Fly-By-Light Aircraft

FLAT-DIMENSIONED INSTRUMENT AND FLIGHT STATUS DISPLAYS FOR MILITARY AIRCRAFT

With the continuing development of advanced avionics systems, there has been an increasing requirement for graphic nonmechanical displays in military aircraft. There also has been concern for the difficulties and large costs associated with retrofitting older aircraft with the deep-dimensioned cathode ray tube (CRT) displays, because of the very limited space available. In view of this, the Flight Dynamics Laboratory, on a jointly shared basis with the Canadian Government, has developed the key portions of a new solid state display technology that may resolve this critical retrofit space problem.

This alternative to present graphic CRTs can be made into any screen size and format required for any given flight vehicle instrument panel application because the display face is made up of square (4-edge abuttable) building-blocks. It does not rely on glass structure or high voltage for its operation. The thinness of the depth dimension afforded by this technology (1.5 to 4 inches) has never been approached by its CRT display counterparts. The first production contract was recently initiated for 390 displays (direct spin-offs from this new technology) for installation in F-16 aircraft.

Flat panel displays have several other desirable characteristics, including a very high (10K hours) potential mean-time-between-failure. Any failures that do occur will tend toward a graceful degradation, rather than the catastrophic type presently experienced with their CRT counterparts. *Unlike the CRT, this new display does not require periodic* flight-line adjustment maintenance. The flat panel display also successfully addresses the USAF's rquirement for equipment standardization.

The flat panel display will play a key role in the coming era of mass application of electronic crew station displays in new and existing military aircraft. The aircraft system designer now has an alternative to the CRT display that has been developed to specifically satisfy military aircraft operational and physical environments. The availability of this technology makes it practical to achieve a significant improvement in effective interface between the pilot and his flight system.

Walter Melnick, AFWAL/FIGR, 513-255-6931

Flat-Dimensioned Multi-Mode Matrix Display

MULTIFUNCTION FLIGHT CONTROL REFERENCE SYSTEM

The Multifunction Flight Control Reference System (MFCRS) is a program to demonstrate through flight test the capability of providing reliable, fault tolerant, and cost effective flight control and navigation outputs from a single, onboard multifunction ring laser gyro inertial reference system. The program, managed by the Flight Dynamics Laboratory, will prove the flight safety aspects of this technology by closed loop operation of redundant, separated ring laser gyro/digital computer packages in an F-15 flight control system.

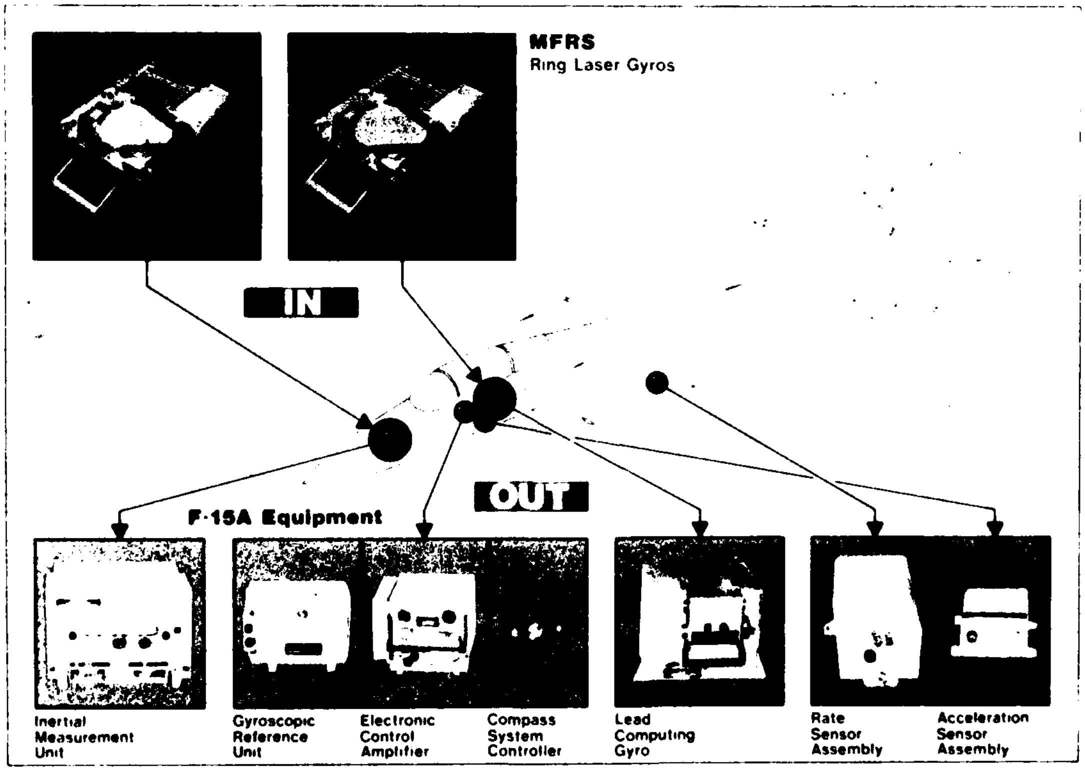
Accomplishment of the program required resolving several key issues related to sensor location compensation, redundancy management, and flight safety. Separation of inertial packages for survivability to combat damage and collocation of gyros and accelerometers for accurate navigation required compensation of aircraft bending modes and lever arm effects at the sensor output. System software employing second order lead-lag filters and notch filters was developed and tested in man-in-the-loop simulations to assure adequate flight control stability, performance, and handling qualities. The utilization of only six gyros and six accelerometers to obtain fail-operate, fail-safe operation required development of a sophisticated redundancy management technique, which was optimized in-house for minimum computer throughput.

Other technical accomplishments included fabrication of the ring laser gyro flight test hardware, development of a technique to reduce ring laser ditherinduced noise to acceptable levels, and development of electronic boresighting to eliminate costly aircraft boresight tools.

Multifunction ring laser systems have significant potential for improving mission effectiveness, system reliability, reaction time, affordability, and combat survivability. For example, use of a dual, dispersed multifunction ring laser system in a tactical fighter increases combat survivability 30 percent by lowering the probability of kill per hit from 9.2 percent (for a non-dispersed system) to 6.4 percent; mean time between failure of 2,000 hours versus 240 hours for a single thread system; and maintenance manhours per flight hour of .25 hours versus .63 hours for current systems. Life cycle cost savings of $365 million are projected based on 1,200 aircraft.

John M. Perdzock, AFWAL/FIGL, 513-255-3686

Multifunction Flight Reference System
Configuration Comparison: F-15A Equipment vs MFRS



Multifunction Flight Reference System
Configuration Comparison: F-15A Equipment vs MFRS

AFTI/F-16 DIGITAL FLIGHT CONTROL SYSTEM FIRST FLIGHT

On 10 July 1982, the first functional check flight of the AFTI F-16 was conducted at Carswell AFB, Texas. This event culminated the development activity, initiated in December 1978, for an advanced digital flight control system (DFCS). The AFTI F-16 testbed also features advanced cockpit displays and controls, a highly integrated avionics system, and new aerodynamic surfaces for advanced control features. Flight testing now underway will develop the core technology which will later be integrated with attack sensors and new automation features for further development efforts. The overall program objective is to develop and flight validate advanced technologies which will improve fighter lethality and survivability.

The combination computer hardware, associated software, and failure management techniques make possible the use of a tri-channel versus conventional quad channel flight control system. The advantages of decreased cost of ownership, weight, and electrical power of the triply redundant system without compromise of reliability will be realized after full development and demonstration of the AFTI/F-16. The AFTI demonstrator, through the DFCS, employs several mission, task-tailored control modes including: normal, air-to-air gunnery, air-to-surface gunnery, and air-to-surface bombing. These modes are implemented in both conventional and in decoupled flight control modes involving direct force control and weapon line pointing. The DFCS permits these changes in the control laws and the flight control modes to be implemented by way of software rather than by hardware. This capability, along with the interface and interchange of data over redundant multiplex data busses with the fire control system and the other avionics, will significantly enhance the lethality and survivability of future fighter aircraft.

The AFTI/F-16 digital flight control system technologies have direct application to the next generation fighter and/or major update of current fighters. The approach being taken will provide critical demonstrations in combat automation that can lead to an automated night attack capability.

Frank R. Swortzel, AFWAL/FII, 513-255-2060

AFTI/F-16 Aircraft

VISCOUS FLOW FIELD COMPUTER PROGRAM

The successful design of future high speed aircraft and missiles will require the continuing development of computation tools to analyze the fluid dynamics of the vehicles. A user oriented numerical computer program based on the solution of the parabolized Navier-Stokes (PNS) equations, has been developed by the Flight Dynamics Laboratory. The PNS program has the capability to accurately compute the viscous flow field over practical three-dimensional shapes at high Mach numbers. The new user oriented program provides a quick and easy method of inputting geometrics through interactive graphics techniques.

Substantial progress has been made recently in the development of advanced numerical flow field computer programs for the design of high speed vehicles. This progress has been in both the completion of numerical wind tunnel studies of advanced Ballistic Missile Office (BMO) configurations and in the establishment of an industry wide user group to further the development and acceptance of this technology. The PNS program has been applied with outstanding success to several BMO biconic missile configurations encompassing the additional complexities of body slices and compressively deflect· a control surfaces. These shapes were successfully computed past their planned operating envelopes with substantial accuracy.

As a result of the Laboratory's success in developing and applying the user oriented PNS program, BMO has selected this program from among all such programs for use in future system developments. BMO has further recognized the Flight Dynamics Laboratory as the national center of expertise in this area, and acknowledged that the Laboratory's capability and contributions are at the forefront of technology.

The Flight Dynamics Laboratory also hosted a workshop for all users of the PNS program to further development of this tool through shared experiences. The workshop was an outstanding success. The user oriented PNS program offers the potential for far greater insight into the aerodynamics of new configurations at a fraction of the cost of wind tunnel testing.

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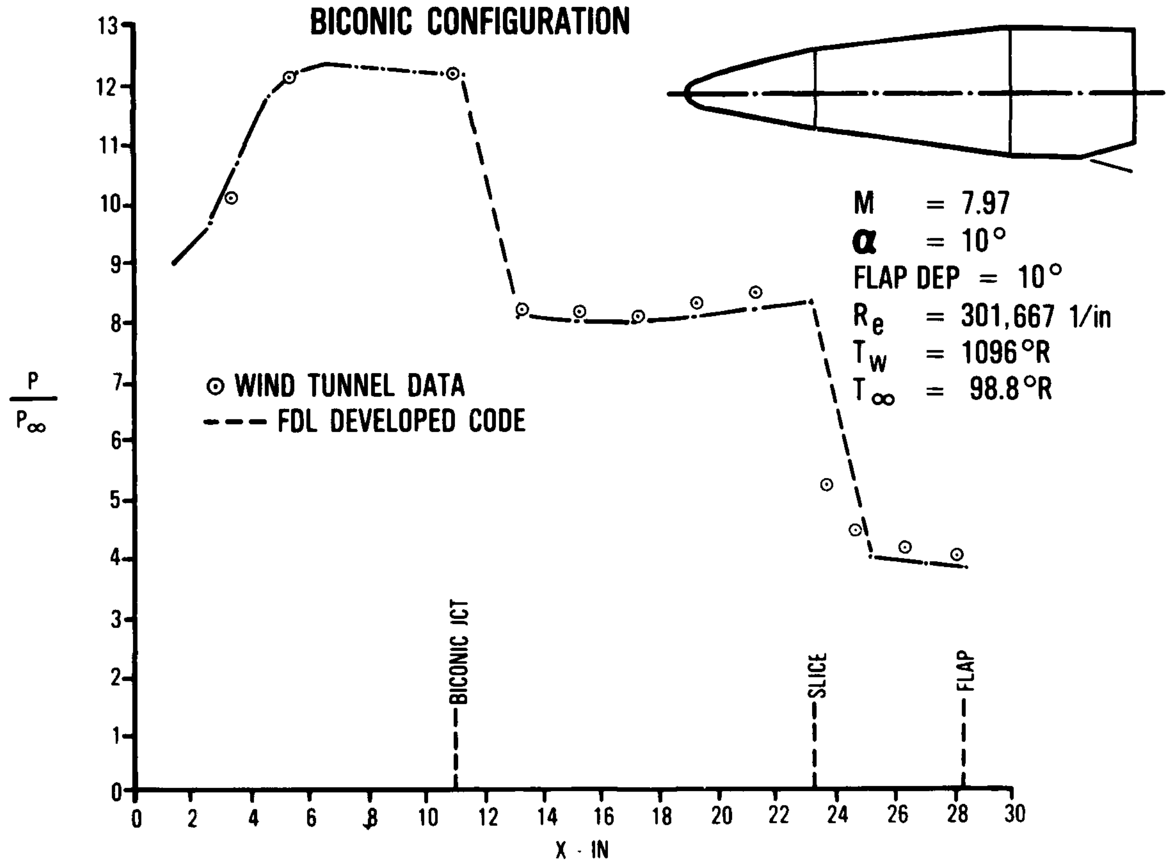

Viscous Flow Field Program

INFLUENCE OF HIGHLY INTEGRATED PROPULSION STREAMS ON AERODYNAMIC PERFORMANCE

Many advanced aircraft will rely heavily on sophisticated integration of the propulsion system to accomplish diverse mission requirements. This blending of the propulsion components and the aircraft contours can create an aerodynamic/propulsion interaction which must be considered in determining total aircraft performance.

Under a Flight Dynamics Laboratory program, wind tunnel tests were conducted on a half-span model of an advanced wing design incorporating a buried propulsion installation, which provided independent control of inlet and exhaust nozzle flows. This unique testing technique enabled engineers to define the influence of the propulsion system operation on the wing aerodynamic performance, and provided data to industry that were never before available.

The model was provided with high pressure air to simulate the exhaust nozzle operation, and with a suction system to provide a simulation of the inlet flow conditions. These systems could be operated independently or in combination to evaluate the impact of the propulsion system operation. The primary inlet and exhaust nozzle configuration variations included three different inlets, a moderate aspect ratio exhaust nozzle, and a thrust reverser configuration. Data were obtained over a range of Mach numbers, angles of attack, nozzle pressure ratios, and inlet flow conditions.

The results demonstrated conclusively that inlet flow variations affected the under-wing pressure distribution aft of 50% chord only when the exhaust nozzle was flowing. This interactive phenomena, coupled with the demonstration of a very substantial effect of inlet-nozzle operation on wing pitching moment, means that future wing design for aircraft of this type will have to be developed integrally with the propulsion system. The work accomplished in this technology program will significantly improve USAF's ability to evaluate advanced aircraft configurations having sophisticated inlet and exhaust nozzle installations without extensive wind tunnel testing.

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Buried Propulsion Wind Tunnel Model

AIR COMBAT CORRELATION ANALYSIS

The analysis of aerial combat often involves consideration of a large scale stochastic differential game. Until recently, such analyses have concentrated on the close in one-on-one encounter rather than the multi-vehicle situation. To provide a more realistic analysis, the Flight Dynamics Laboratory has developed a computer simulation that relates air combat effectiveness to aircraft design parameters in a many-on-many (M-on-N) environment.

The "MULTAC" (Multiple Tactical Aircraft Performance Evaluation) program is a computerized method for analyzing the outcome of an air combat encounter between two opposing forces, involving up to 20 aircraft. The program is sensitive to the number and type of aircraft on each side; their respective vehicle performance characteristics; the quantity and type of weapons available; the initial status (relative altitude and positions) of the aircraft within the airspace; and pilot tactics.

Recently, quantitative correlations were made between the MULTAC program and AIMVAL/ACEVAL flight data. Two hundred and fifty three one-on-one through four-on-four encounters from the AIMVAL/ACEVAL exercise were simulated in MULTAC and the results compared. The data show that stochastic effects dominate outcomes and that air combat performance estimates should be based on a large sample of encounters. Overall exchange ratios (the number of "red" losses per "blue" loss) predicted by flight test and analysis are within 5% of each other.

The most significant point demonstrated from the air combat correlation analysis is that the use of one-on-one exchange ratios to predict the outcome of large scale encounters is inappropriate. Rather, the exchange ratio is a function of force size and force size ratio. To obtain force size exchange ratios, the particular aircraft/weapon combination requires an analysis in an M-on-N environment. The MULTAC code provides such an analysis technique. The successful correlation work accomplished with the MULTAC program has improved air-to-air analysis capability, and contributed to the air superiority and intercept effectiveness of future fighter aircraft.

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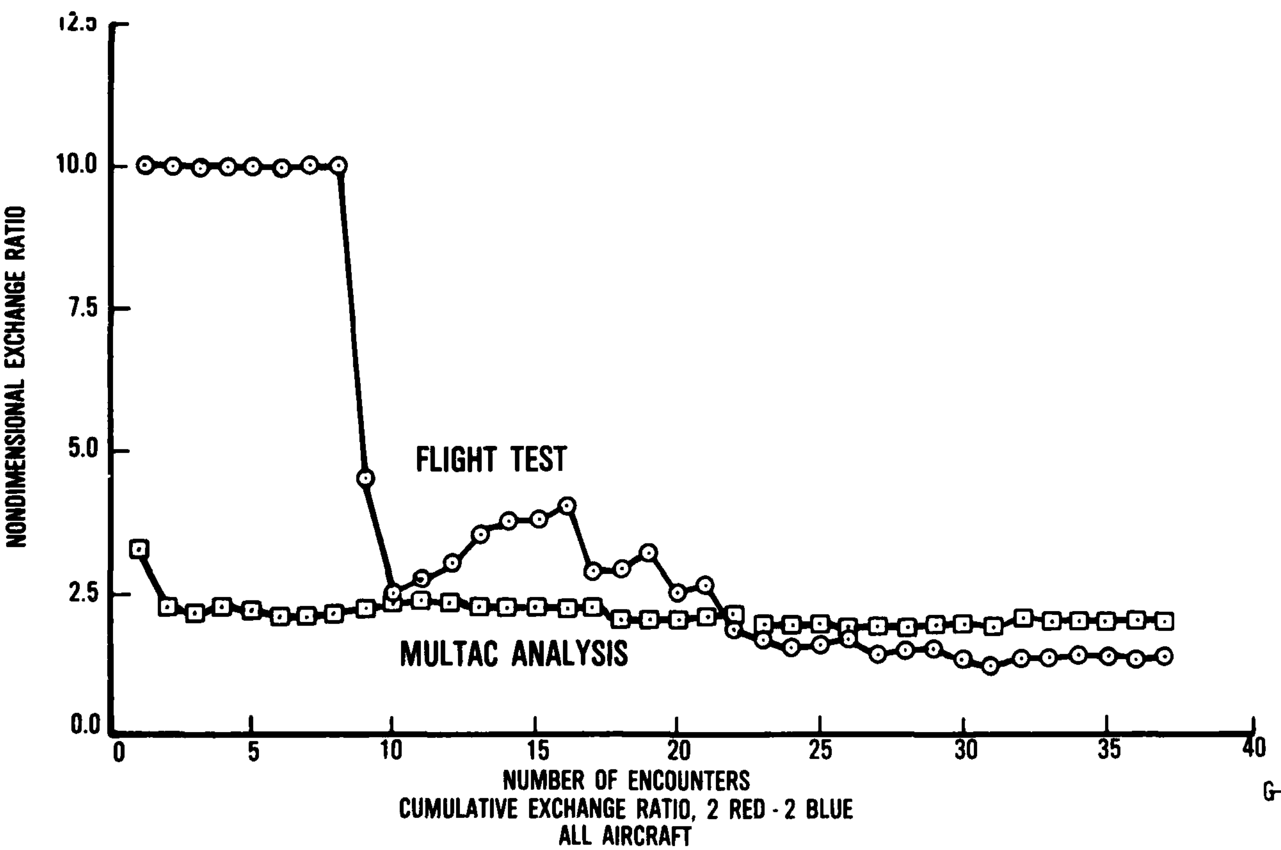

Comparison of Air Combat Correlation Results

ADVANCED NOZZLE CONCEPTS

In designing future tactical fighter aircraft, the trend is toward attempting to maintain the maximum speed and maneuverability of current fighters while imposing additional requirements for sustained supersonic speed and short takeoff and landing capabilities. The Flight Dynamics Laboratory has completed a technology program which has shown that advanced, highly integrated nozzles with the capability to vector and reverse thrust have the potential to help satisfy these conflicting performance requirements.

The ANC technology program has established that advanced multi-function nozzles can be integrated into advanced air-to-surface and air-to-air supersonic tactical aircraft resulting in large increases in aircraft mission capability. For air-to-surface aircraft, the multi-function nozzle reduced the maneuver drag by 10 percent, provided significant levels of independent fuselage control, and an 87 percent reduction in in-flight deceleration time. Most significantly, this aircraft was able to meet a 1,400 foot matched field length STOL capability with no increase in take-off gross weight.

The advanced multi-function nozzle also provided the air-to-air aircraft with an 18 percent reduction in maneuver drag, independent fuselage aiming, up to 6.5 g's of direct lift, and a 74 percent reduction in in-flight deceleration time. The STOL application for this aircraft was equally impressive with less than a 1,000 foot matched field length obtained with no increase in aircraft take-off gross weight. Not only were the payoffs identified for these aircraft, but design criteria to efficiently integrate these nozzles in future aircraft was defined.

The ANC program established the practicality and feasibility of utilizing advanced multi-function non-axisymmetric exhaust nozzles for future air-to-surface and air-to-air supersonic tactical aircraft. It also defined utilization payoffs for these nozzles showing benefits of thrust vectoring and thrust reversing for air combat maneuvering, STOL applications, and in-flight deceleration. As a result of this program, preliminary design engineers have guidelines for successful nozzle integration and utilization.

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Advanced Nozzle Concept Wind Tunnel Model

SECTION IV
MATERIALS LABORATORY

CHEMICAL COMPOSITION CONTROL OF EPOXY RESINS

Historically, the quality control (QC) of organic resin base structural composites was based solely upon in-process QC and the mechanical testing of specimens. Also, the chemical composition and process history of the resin matrix was a proprietary area, very closely guarded by the materials suppliers.

The chemical composition thrust involved six Materials Laboratory contracts with corporations such as Rockwell, Grumman, McDonnell Douglas, General Dynamics, and Lockheed to develop the analytical techniques and procedures as well as the required scientific methodology to control the chemical composition of epoxy resins currently in use on Air Force weapon systems. This work was very successful. All of the materials suppliers, though extremely hesistant at first, ultimately provided their fullest cooperation. Compositional specifications for epoxy resins are now in use throughout the industry for both aircraft and space applications. This effort has been a strong positive factor in advancing the state of the art of structural composite materials by providing a sound technological basis for materials quality control.

The Materials Laboratory has also sponsored the transition of this technology into a completely automated resin materials quality control center. The center, installed at the General Dynamics F-16 composites production facility in Ft. Worth, Texas, has been in operation for several months, and is now successfully providing automated, rapid, low-cost quality control for epoxy resin composites. NASA and the Army have also adopted this technology for use in commercial and military helicopters, respectively.

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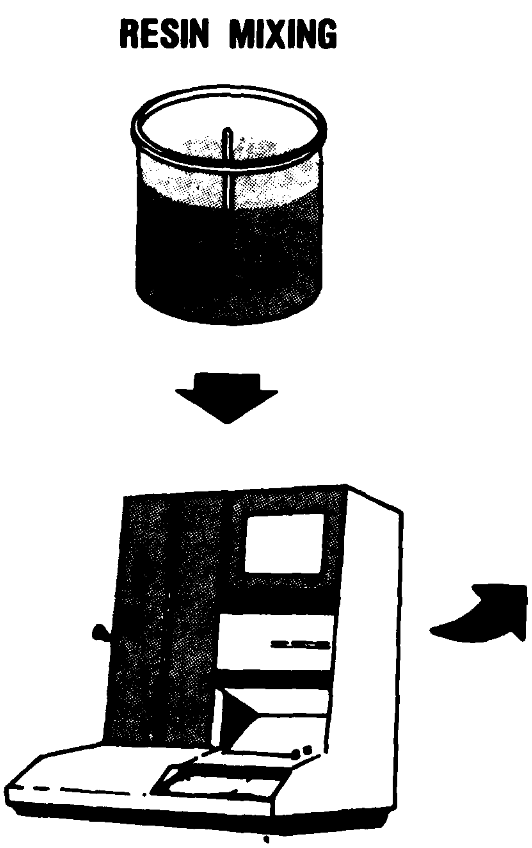
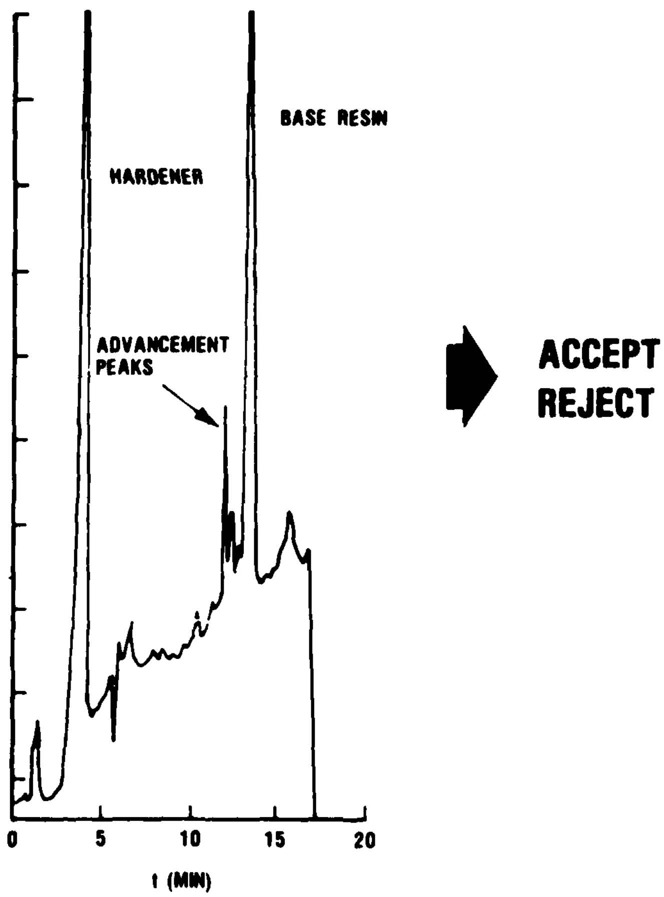


Liquid Chromatograph



Reverse Phase LC Chromatogram of 3501-5A Resin

PROCESS MODELING AND PRODUCT-QUALITY PREDICTION

The forging, extrusion, rolling, and sheet-metal forming industries are characterized by antiquated equipment, a shortage of well-trained persons at all levels, long lead times, and poor equipment utilization. To increase productivity in defense-oriented industries, a team of Materials Laboratory contractors headed by the Battelle Columbus Laboratories and Materials Laboratory in-house scientists and engineers developed and evaluated a powerful and efficient software program called ALPID (Analysis of Large Plastic Incremental Deformation). ALPID is used to predict working loads, tool stresses, and temperature-, stress-, velocity-, and strain-fields which occur in engine and airframe structural components during their manufacture. Also, it constitutes the most essential part of any CAD/CAM system concerned with accurately manufacturing dies, rolls, and associated equipment for rapidly producing parts-on-demand. It provides a more accurate solution to metalworking problems than slab, slip-line, or upper-bound methods. This analytical approach has already been used to develop the first adaptive controlled brake press for the ASD 4950th Test Wing. The brake press has been set for manufacturing, and sheet-metal parts can now be produced without requiring iterative trial runs to make a finished part. Other applications of this technology now in progress are: 1) the development of a forging system to achieve a controlled strain distribution in nickel-base turbine disks to obtain optimum low-cycle-fatigue properties, and 2) the design of streamlined extrusion dies for making aluminum alloy-silicon carbide whisker-powder-material structural components for the Advanced Metallic Structures Program of the Flight Dynamics Laboratory.

A benefits analysis for the application of this advanced technology indicates the following potential payoffs: improved productivity of about 35 percent, reduced delivery times of 50-70 percent, increased equipment utilization of 50-70 percent, reduced forging cost of 30-50 percent, improved product quality, reduced need for capital investment, reduced need for skilled tool-and-die makers by approximately 40 percent, and enhanced strategic materials and energy conservation.

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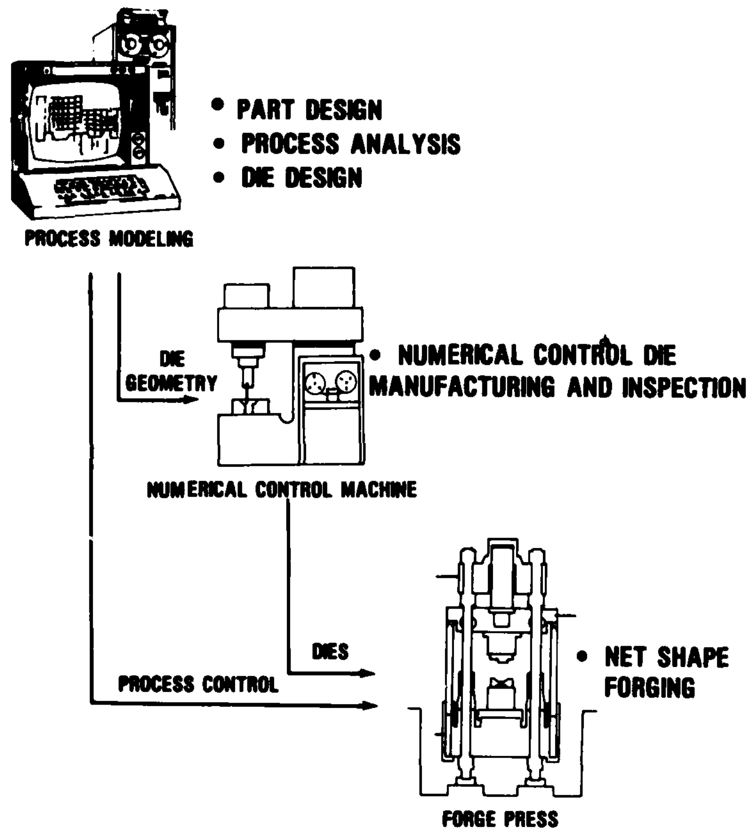

Computer-Aided Engineering

HIGH STRENGTH, HIGH MODULUS POLYBENZOTHIAZOLE FIBERS

High performance composite materials, formed from polymeric resins reinforced with high strength and stiffness fibers, are currently being utilized as structural materials in weapons systems such as the F-15 and F-16, and in other DoD applications. Reinforcement fibrous materials commonly employed in light weight, cost-effective composites include carbon, glass, and Kevlar. An advanced class of polymeric reinforcements is currently under development by Materials Laboratory contractors. Celanese Research Corporation and E I DuPont Corporation are developing fiber-forming and post-treating processes for a high-potential fiber system based on polybenzothiazole (PBT), an outstanding example of "rigid-rod, extended chain" polymers. Polymer synthesis is by SRI, International, based on an in-house Materials Laboratory development. All property goals for these efforts are being met, with combinations of demonstrated strength and stiffness not previously achievable in any polymeric fiber, and rivaling carbon fiber properties at 15 percent lower density. Fibers demonstrating over 500,000 psi tensile strength and 50 million psi Young's modulus have been obtained reproducibly, with high valves over 600,000 tensile and 55 million modulus not unusual. In addition to these outstanding mechanical properties, PBT fibers exhibit excellent resistance to damage by moisture and/or high temperature exposure. The fibers are nonconductive electrically, suggesting applications requiring electromagnetic transparency in which carbon cannot be used.

On-going development efforts are concentrating on defining the full envelope of property combinations attainable, as well as emphasizing those process parameters, such as fiber/yarn size and processing speeds, essential to a commercially viable system.

High performance composite materials, based on PBT reinforcements, will provide the Air Force with superior structural materials for advanced weapons systems, which possess the strength and stiffness of conventional carbon fiber based materials at lower weight. Other potential applications areas include electromagnetically transparent structures and light weight, high performance structures for ballistic protection.

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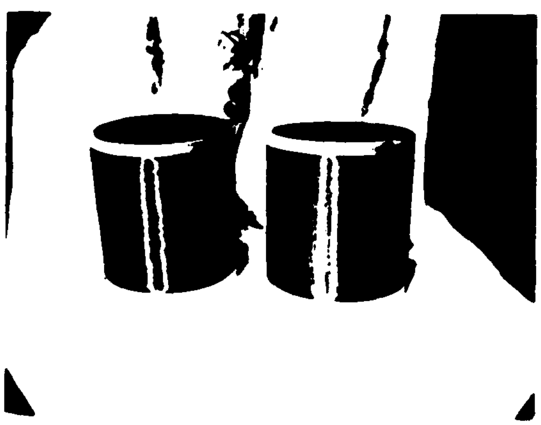
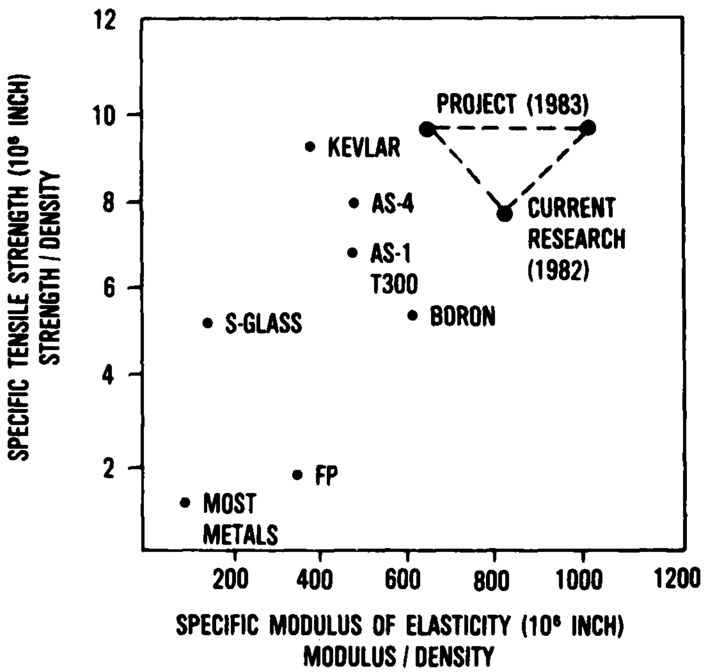


PBT SPOOLS

SPECIFIC PROPERTIES OF AEROSPACE STRUCTURAL FIBROUS MATERIALS



PRODUCTION WELDBOND

More than 1,000 fuselage panels for the A-10 aircraft have been manufactured by a new method without rivets. The panels are weldbonded — joined by a computer-controlled process in which spot-welds are made on the panels through a strong adhesive and then oven-cured to attain the strength and fatigue characteristics required for structural integrity. In the first extensive flight evaluation of any weldbonded components, more than 200 A-10s are flying with the weldbonded fuselage panels. The total A-10 production run will include more than 1,500 panels which will provide a solid data base for statistical service evaluation of weldbonded panels.

Fairchild Republic Company, under a Materials Laboratory contract, did the weldbonding on a pilot production process line at its Hagerstown, Maryland manufacturing facility. Earlier manufacturing process work on weldbonding for aerospace structures was funded by the Materials Laboratory at Northrop Corporation, Hawthorne, California and at Lockheed-Georgia Corporation, Marietta, Georgia.

Weldbonding has several advantages over conventional joining techniques. It is energy efficient and costs less because it requires inexpensive tooling and is less labor-intensive.

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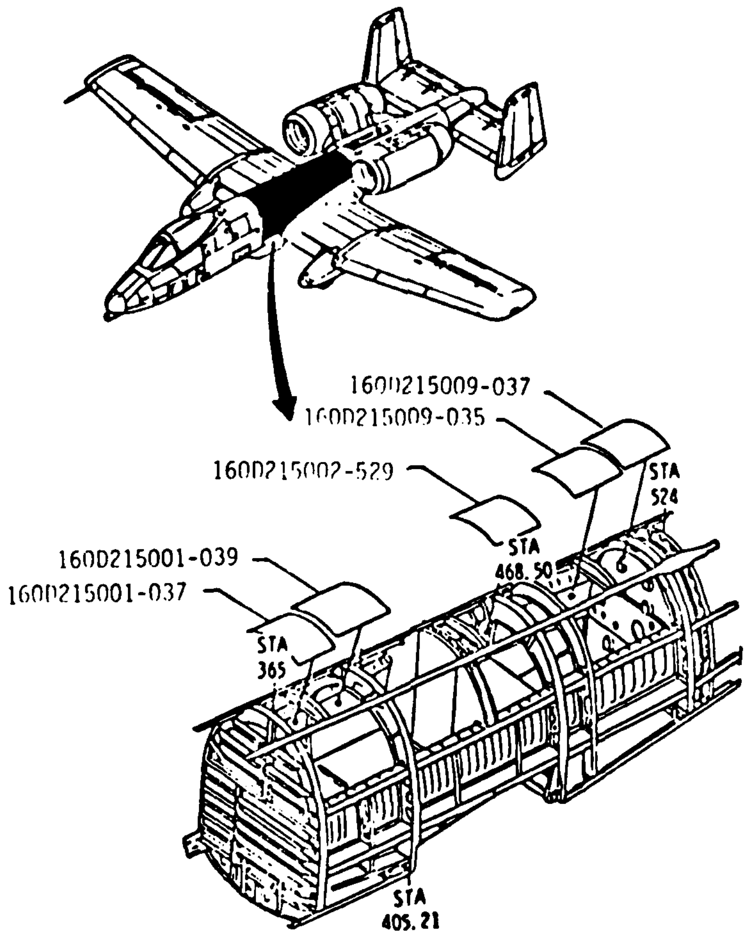

Production Weldbond Fuel Cell Access Doors

FAILURE ANALYSIS OF F-16 LINEAR FEEDBACK POTENTIOMETER

Five F-16 aircraft at McDill AFB experienced serious malfunctions in the nose wheel steering system. All failures occurred during taxi and resulted in the nose wheel turning hard right. The F-16 System Project Office submitted the failed potentiometers to the Materials Laboratory for failure analysis. In all cases, the malfunction was caused by a low resistance path between the output pins and the potentiometer case. Failure analysis identified corrosion product contamination of the glass header which insulates the input/output pins from the potentiometer case. The corrosion residue was sufficiently conductive to cause an electrical short between the pins and case. These potentiometers are currently used on numerous aircraft and possess high failure rates in nearly every application. The Materials Laboratory recommended that potentiometer improvements be incorporated into the nose wheel steering system for all aircraft currently using these potentiometers, however, this modification is only being done for the F-16 by General Dynamics. In an effort to eliminate this problem from other aircraft, the Materials laboratory has discussed the problem with the Air Force Logistics Command PRAM Office and is seeking their support to introduce the fix into other systems which use this potentiometer.

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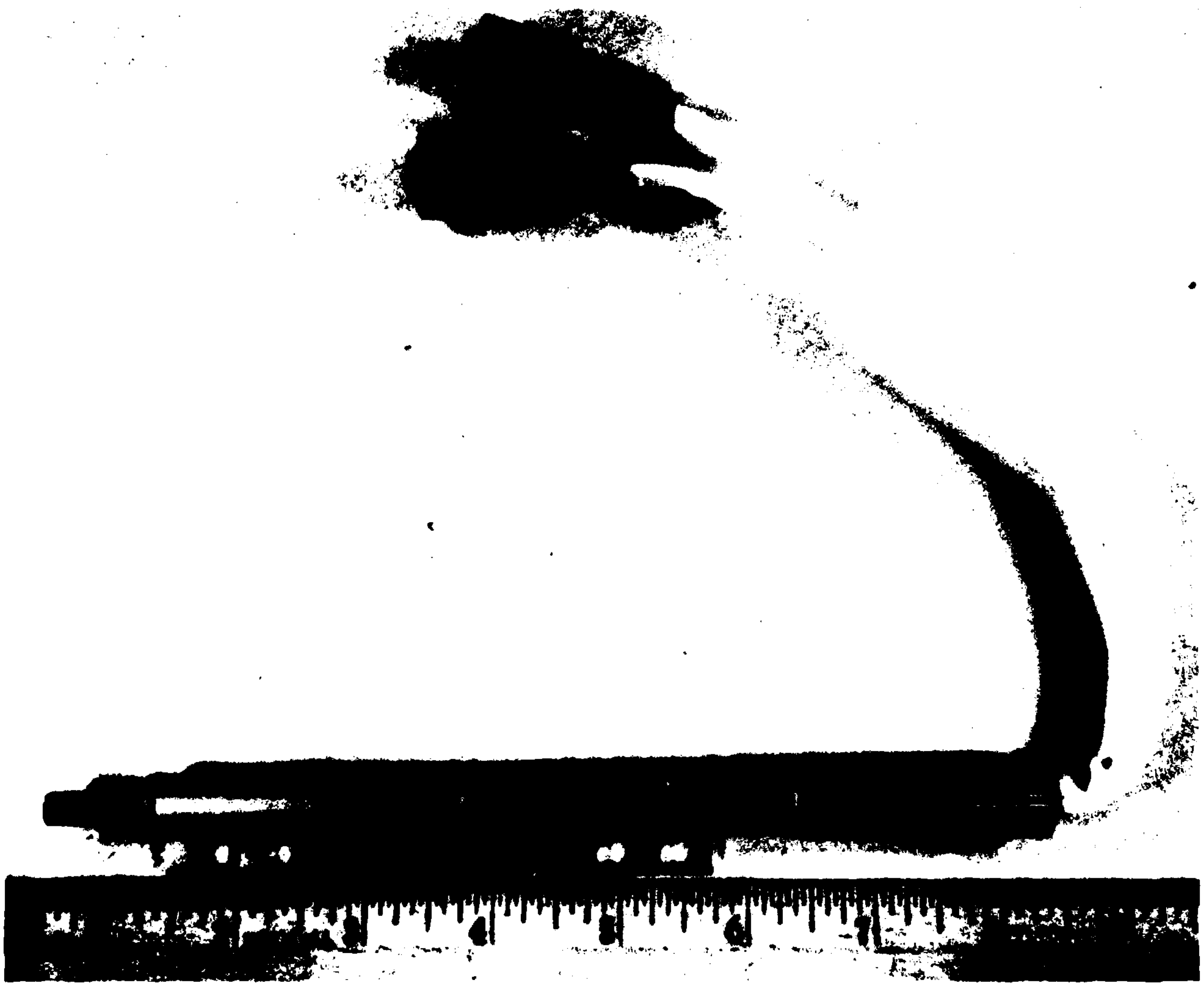

F-16 Nose Wheel Steering System Linear Feedback Potentiometer

SYNTHETIC HYDROCARBON LUBRICANTS

For the past 15 years, gyroscopes have been lubricated by a very special highly refined mineral oil extracted from virgin crude oil found in ever-diminishing locations in this country. These gyroscopes have been the heart of the navigation platforms for DoD aircraft, satellites, and the space shuttle. The high degree of accuracy is greatly dependent on the reliability of the gyro wheel spin axis bearings which must be lubricated for rotation of up to 24,000 rpm for as much as seven years. The cost of lubricants for such uses has increased steadily over the last 20 years and now exceeds $500 per gallon plus an additional $24,000 refinery charge.

Recognizing this serious situation, the Materials Laboratory initiated an in-house program to develop a replacement lubricant. The most promising lubricant that emerged from this program is a synthetic hydrocarbon made from alpha olefins. Although these alpha olefins are still derived from petroleum, they are not restricted to special crudes nor do they require special refining. These synthetic hydrocarbons are produced by recognized methods from feed stocks that are the backbone of the petrochemical industry and are expected to lower the price to less than $75 per gallon. Significantly, the Materials Laboratory progr ım demonstrated equivalency of the synthetic hydrocarbons to super refined mineral oils in all conventional properties and superiority in low temperature bearing torque tests for all viscosity grades.

The influence of synthetic hydrocarbon lubricants on gyroscope motor bearing life is now being determined under an Air Force program initiated at the Aerospace Guidance and Metrology Center, Newark Ohio Air Force Station. Forty gyros of three different designs are being used to conduct life tests comparing the synthetic hydrocarbon lubricants with the currently used super refined mineral oil equivalent viscosity grade lubricants. To date, one group of gyroscopes has operated continuously for more than 1,500 hours without any failures.

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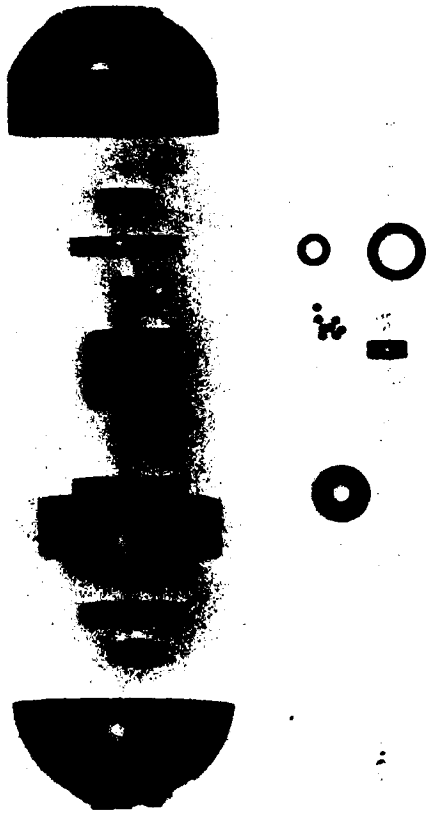

Typical Gyroscope Application for Synthetic Hydrocarbon Lubricants

EXTERNAL FUEL TANK LEAK REPAIR

The Materials Laboratory has successfully completed the development of two methods of externally patching fuel tank leaks occurring around fasteners. A Laboratory development effort was first conducted in-house. This effort identified several primary approaches and, through testing, it was found that adhesively bonding an aluminum patch or applying an epoxy putty over the leak were the two best approaches. Field tests were conducted to evaluate these approaches by the USAF Airlift Center, Military Airlift Command, Pope Air Force Base. The final reports on the logistics service tests both dated August 1981, recommended adoption of both the adhesive bonded aluminum patch and the epoxy-putty method for repairing classes A, B, and C fuel leaks as defined in T.O. 1-1-3. The impact of implementing these repair methods will be: increased aircraft availability; no defueling is needed; repairs can be made from -10° to +140° F; and repairs can be quickly made on the flight line using little support equipment. The operating commands will have improved readiness capability through use of temporary leak repairs since a permanent repair can be delayed until regularly scheduled depot maintenance is required.

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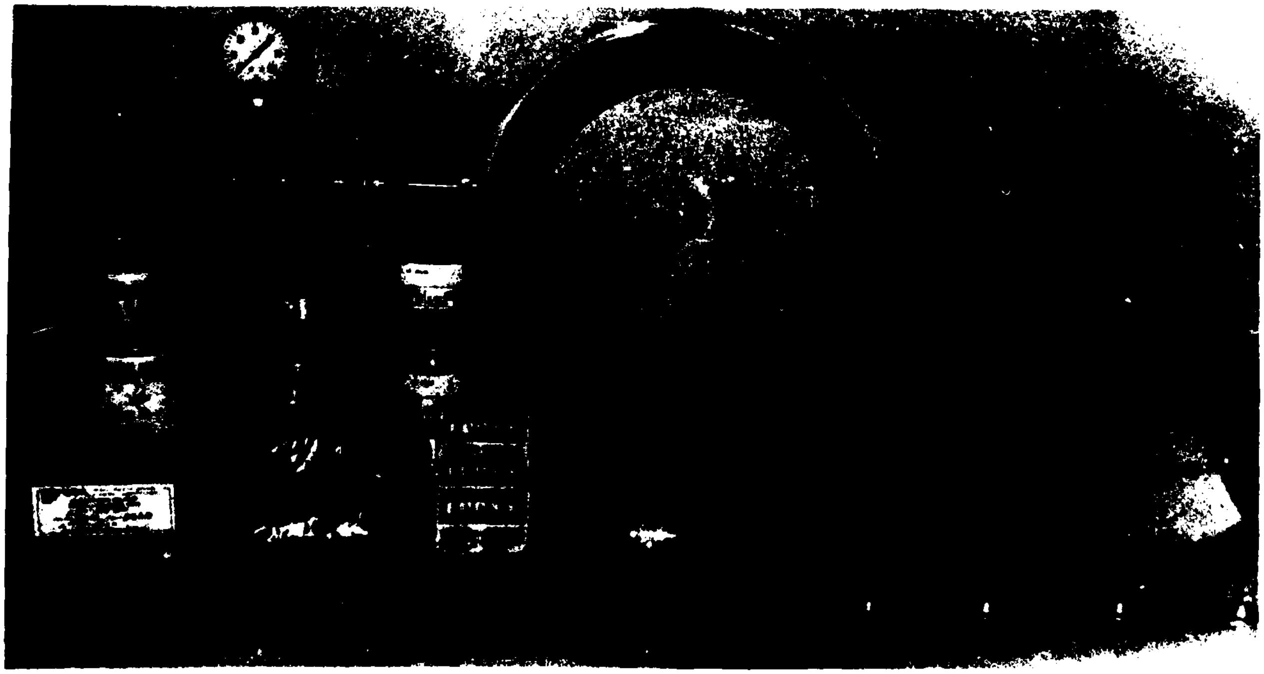

External Fuel Tank Leak Repair Test Equipment and Materials

LITHIUM BATTERIES

The need exists for batteries with enhanced low temperature capability for use in life support equipment like transceivers and rescue beacons. The enhanced capability is desirable since the performance of all batteries degrades at low temperatures, particularly mercury cells which are currently used in all survival equipment. These mercury cells provide no power below 0° F. Lithium batteries, in comparison, permit up to five hours of operation at -40° F. Another advantage is that the lithium battery (4 oz) contains the same energy as three mercury cells (17 oz). Manufacture of lithium batteries, however, did provide some problems.

Under a Materials Laboratory contract, Honeywell-Horsham, Pennsylvania developed, evaluated, and set up a production line for the manufacture of four standard sizes of non-reserve lithium-sulfur dioxide cells. The sizes were AA, A, C, and D/2. The production line was to produce cells at a cost that is competitive with alternative products and 50 percent less than the available over-the-counter lithium cells. Knowledge about hermetically sealed lithium cell performance was limited. As data were accumulated through the first engineering prototype, it became clear that, although lithium-anode cells offered a quantum-jump improvement over existing cell types, the lithium-sulfur dioxide system presented hazards not encountered with more conventional batteries. Specific problems were safety hazards resulting from residual lithium at the end of discharge, and the possibility of explosion during forced discharge. These problems were overcome by the evolution of a lithium limited, hermetically sealed cell designed to rupture and vent before explosive pressure could develop. The "safe" lithium limited design has storage capabilities from -60° F to +205° F and meets the requirements for life support missions, particularly with respect to safety and environmental capabilities. It is now entering the inventory.

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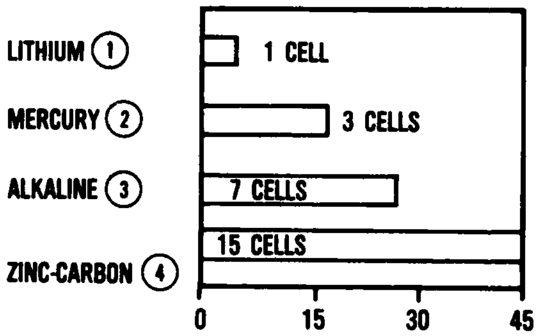

Figure 1

Equivalent Energy Room Temperature

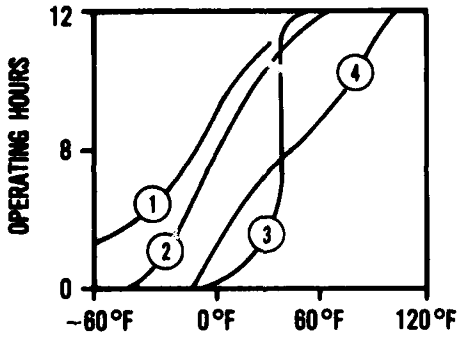

Figure 2

Low Temperature Performance

ADAPTIVE CONTROLLED LASER DRILL AND INSPECTION

Since 1970, the laser has been used to drill small holes in production engine parts of high strength, high temperature metals. Between 1973 and 1975, a cost effective small hole drilling process was established to produce large depth to diameter (L/D) ratios with a high degree of confidence for use in highly stressed parts.

The General Electric Company, Cincinnati, Ohio, under a Materials Laboratory contract, recently expanded the utilization of laser drilling, improved laser drilling reproducibility, and reduced manual inspection to reduce the cost of air-cooled aircraft engine components. These improvements were accomplished by establishing an adaptive controlled laser drill and inspection system and increasing the penetration capability of laser drilling. The adaptive controlled laser drill and inspection system was completely successful with a threefold increase in laser drill capability achieved. A "remote" lens positioning method established during this program permitted the use of a single laser medium, Nd/YAG, for the majority of holes of interest. This method reduced the required number of pulses for penetration by 40% and produced higher quality holes. Use of this system on an engine such as the F-101 is expected to result in a cost savings of $37,000 per engine in hole generation and inspection costs.

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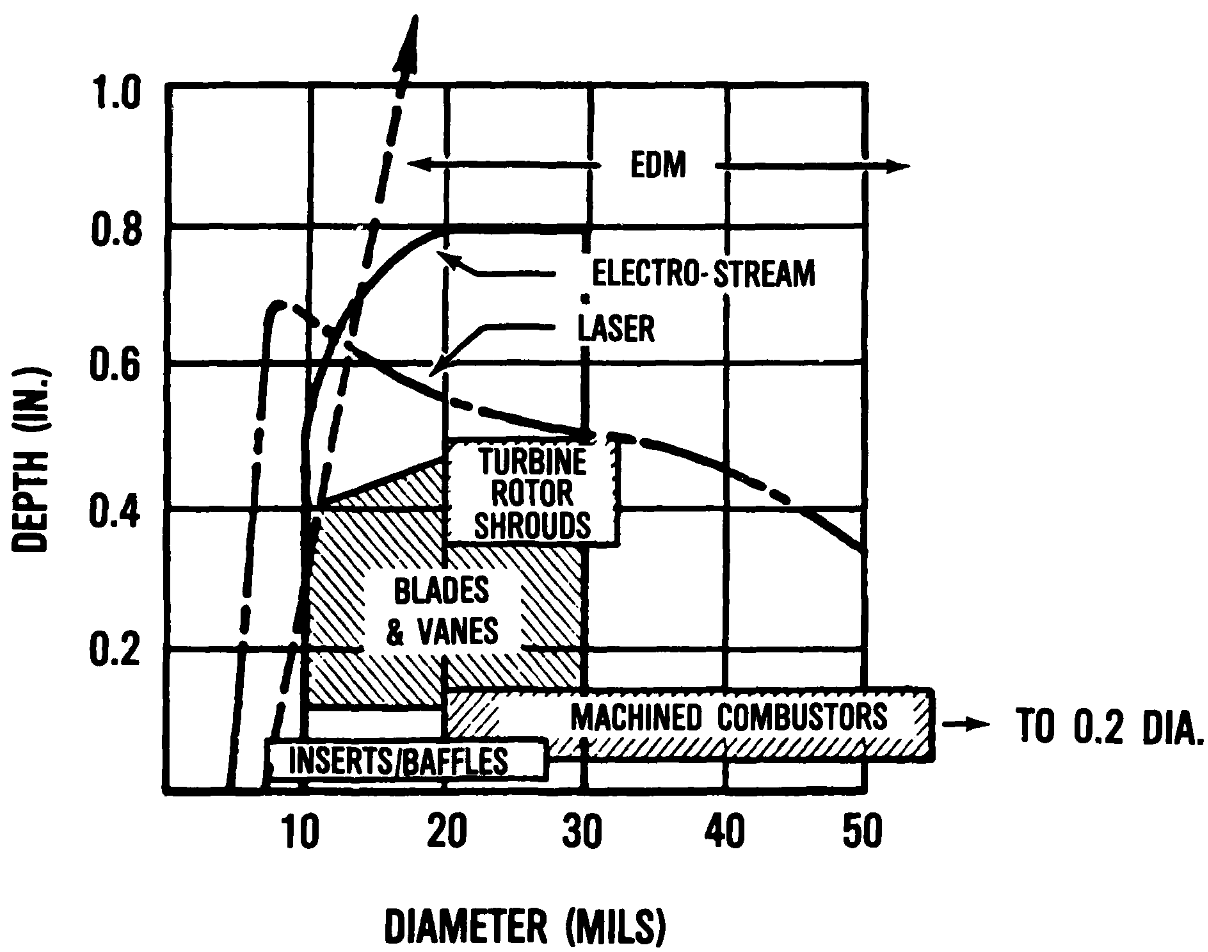

Depth and Diameter Region of Nonconventional Drill Processes

COMPOSITES CONTOUR PART LAMINATING

Grumman Aerospace, Bethpage, New York, under a Materials Laboratory contract, demonstrated a low cost generic manufacturing concept, the Automated Integrated Manufacturing System (AIMS), for fabrication of composite contoured engine ducts. This program has produced many industry firsts, including an automatic process for contour ply laminating of composite prepreg and an automatic stitching machine for contoured composite aircraft components. To validate the manufacturing concept, Grumman fabricated 100-inch long composite engine inlet sections for their Advanced Tactical System. The equipment demonstrated on this program included the automated composite prepreg fabric dispenser, the automated contour ply laminator, and the automated stitching machine. The inlet frames and hat stiffeners were nested, cut, and installed on the inlet skin. Hat stiffeners and frames were stitched to the inlet skin (before curing) using the automatic stitching machine. At the projected production rate, a return on investment break-even point is reached in three years.

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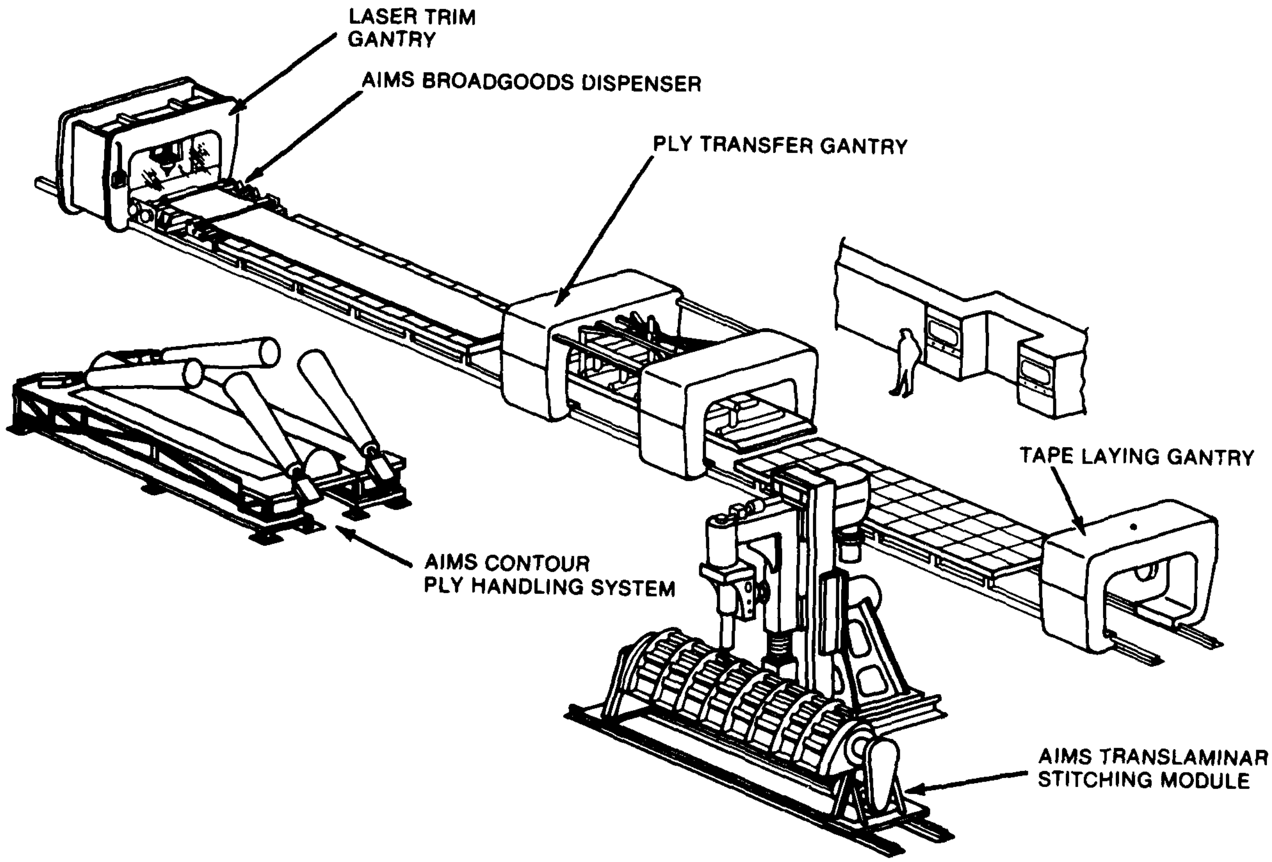

Automated Integrated Manufacturing System (AIMS)

AUTOMATED ELECTROCHEMICAL MACHINING

Electrochemical machining (ECM) is the controlled removal of metal alloys by anodic dissolution in an electrolytic cell. In the traditional use of ECM, the process parameters are held constant throughout a machining cycle. This practice has disadvantages in that a given set of parameters may not be optimum for the entire cut duration. The response variables change as the electrode enters a cut, cut areas increase, internal electrolyte flow passages change, and thermal energy is released into the machining cell due to IR heating. Although minor changes of the operating parameters can be made by manual adjustments on existing machines to compensate for these changes, an automatic method of parameter regulation is required to maintain optimum conditions in the machining cell.

An automated electrochemical machining system has been established by the General Electric Company, under a Materials Laboratory program, for generating airflow passages and curved dovetail slots in bore-entry cooled turbine rotor disks. Operating methods are used which vary the electrode feed rate, electro-potential, and electrolyte pressure to maintain optimum process conditions during machining. The system is under the direction of a computer base controller which implements the machining programs and performs data logging functions. The controller also monitors critical process parameters to assure process repeatability during production operations. One disk prototype was machined and the cost savings potential of the automated ECM method of manufacture is estimated at $24,880 per single disk.

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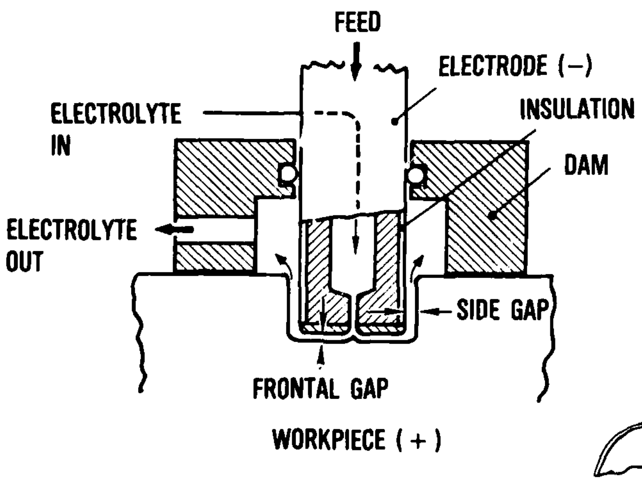
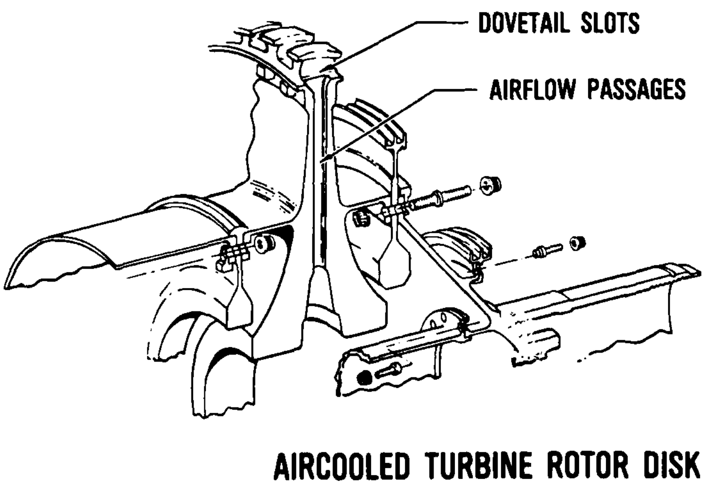


ELECTROCHEMICAL MACHINING CELL



AIRCOOLED TURBINE ROTOR DISK

EDDY CURRENT SURFACE INSPECTION OF ENGINE DISKS

General Electric-Cincinnati, under a Materials Laboratory contract, prototyped a highly automated eddy current inspection system known as EC-I, for disks and other rotating engine parts. Manual and semi-automated techniques were adapted to control probe manipulation, crack detection, and data interpretation. This eliminates or minimizes the effects of variables and operator technique on the inspection results. The sensitivity of the prototype system as it scans the complex geometries associated with stress concentrations (such as bolt holes, dove tails, and fillet radii) will permit parts to be removed from service on a "for cause" basis rather than on engine operating time, which is the current practice. This system represents a significant step toward a fully automated eddy current inspection system for rotating parts. The manipulation consists of translation and rotation of the disk on the inspection table and vertical and rotary motion of the probe. The system has demonstrated the capability to detect flaws smaller than the required 0.030 inches long by 0.005 inches deep. The system was installed at Kelly AFB, Texas, for evaluation by operators from there and from Tinker AFB, Oklahoma and is now assigned to the Retirement for Cause/Nondestructive Evaluation program. Two pre-production systems have been completed as a follow-on program. These systems, known as EC-II, are being installed at Kelly and Tinker engine maintenance facilities. These pre-production systems will provide automatic scanning, signal processing, decision-making, data storage, and preparation of print-out reports showing locations of detectable flaws. The manipulator provides six axes of encoded motion and the rotating probe provides the seventh. This design allows the system to inspect any geometric surface and report the flaw locations. Additonal features of the pre-production systems include a self-teach mode, automatic re-calibration of the eddy current instrumentation using piece parts standards, and a simplified, semi-automatic evaluation routine. The eddy current inspection probes are designed for self-compliance to the part; both universal type and specialized probes will be used and will be exchanged manually. The equipment can handle parts up to 200 pounds in weight and 44 inches diameter by 20 inches high at scan rate of 1-2 inches per minute.

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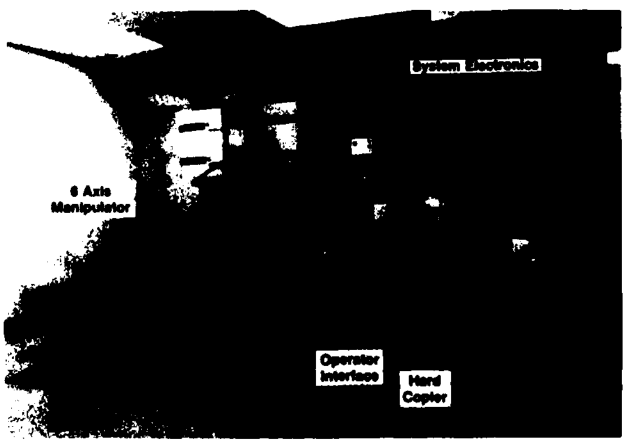
Eddy Current EC-I Prototype



Eddy Current (EC-II) Pre-Production System

LAMINATED WING STRUCTURES

General Dynamics, Fort Worth Division, under contract to the Materials Laboratory, designed a laminated wing skin and demonstrated the manufacturing techniques for producing this aluminum primary wing structure. This concept is particularly attractive for airframe members which experience repeated tension loads of high magnitude such as an aircraft wing lower surface skin. Damage tolerance is achieved through inherent multiple load paths, crack arrest, and load transfer capabilities. An 18 sq. ft. section of the F-16 inboard wing lower surface skin was built to demonstrate the potential of laminated construction. The wing successfully passed static strength, durability, and damage tolerance testing while demonstrating improved in-service inspectability, maintainability, and overall reduced cost of ownership. A production wing for the F-16 using the laminated wing skin shows a projected savings of 10 percent in cost and 6 percent in weight.

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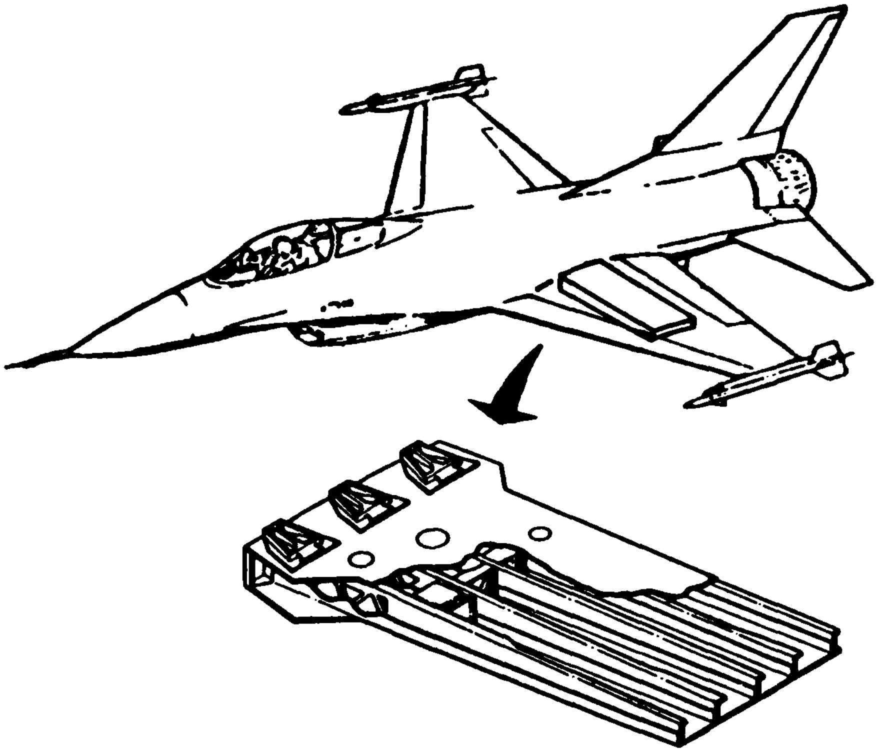

Laminated Wing Structure Program (F-16)

COMPOSITE MISSILE LAUNCHER SHAFTS

The Boeing Company, Wichita, Kansas, under contract to the Materials Laboratory, established and validated manufacturing methods and quality assurance procedures applicable to the fabrication of advanced composites thick-wall cylindrical shafts. A ten-foot section of a cylindrical shaft with a diameter and wall thickness relevant to an advanced rotary launcher system shaft was fabricated as a demonstration article. A cost and weight benefit analysis indicates that a composite shaft would provide an approximate 50 percent weight savings (5,000 lbs. in a B-52 application) over a full scale base line metal shaft and would be at least cost competitive. Based on the results of this program, a composite tube is the primary contender for a launcher system identified for the B-52/LRCA/advanced bomber launcher program sponsored by the Air Force.

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PRINTED WIRING BOARD ELECTRODEPOSITION PROCESS

Effective, efficient, and dynamic process controls for analyzing and controlling printed wiring board (PWB) electroplating processes have been accomplished under an Materials Laboratory contract performed jointly by two Rockwell International Corporation Divisions, Electronics Research Center, and Interconnect Systems Division. Emphasis of the program included the optimization of both cyclic voltammetric stripping (CVS) and rotating cylinder (RC) technologies for dynamically analyzing and controlling the copper pyrophosphate electroplating operation. The CVS and RC techniques were coupled with a unique plated-through hole agitation evaluation technique to define and optimize PWB plated-through hole production plating bath variables. Rockwell's large PWB Cedar Rapids facility successfully implemented the program results. Yield improvements for complex multilayer PWBs were increased by greater than 10 percent in Rockwell's copper pyrophosphate PWB plating operations. The value of dynamic process control capability was firmly demonstrated via timely detection of detrimental bath contaminants, variations in organic additives of ±0.05 percent, and sporadic production problems resulting from faulty filter cartridges and bad anode materials. Rockwell has licensed the CVS technology to Unit Process Assemblies of Syossett, New York for widespread PWB industry utilization.

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